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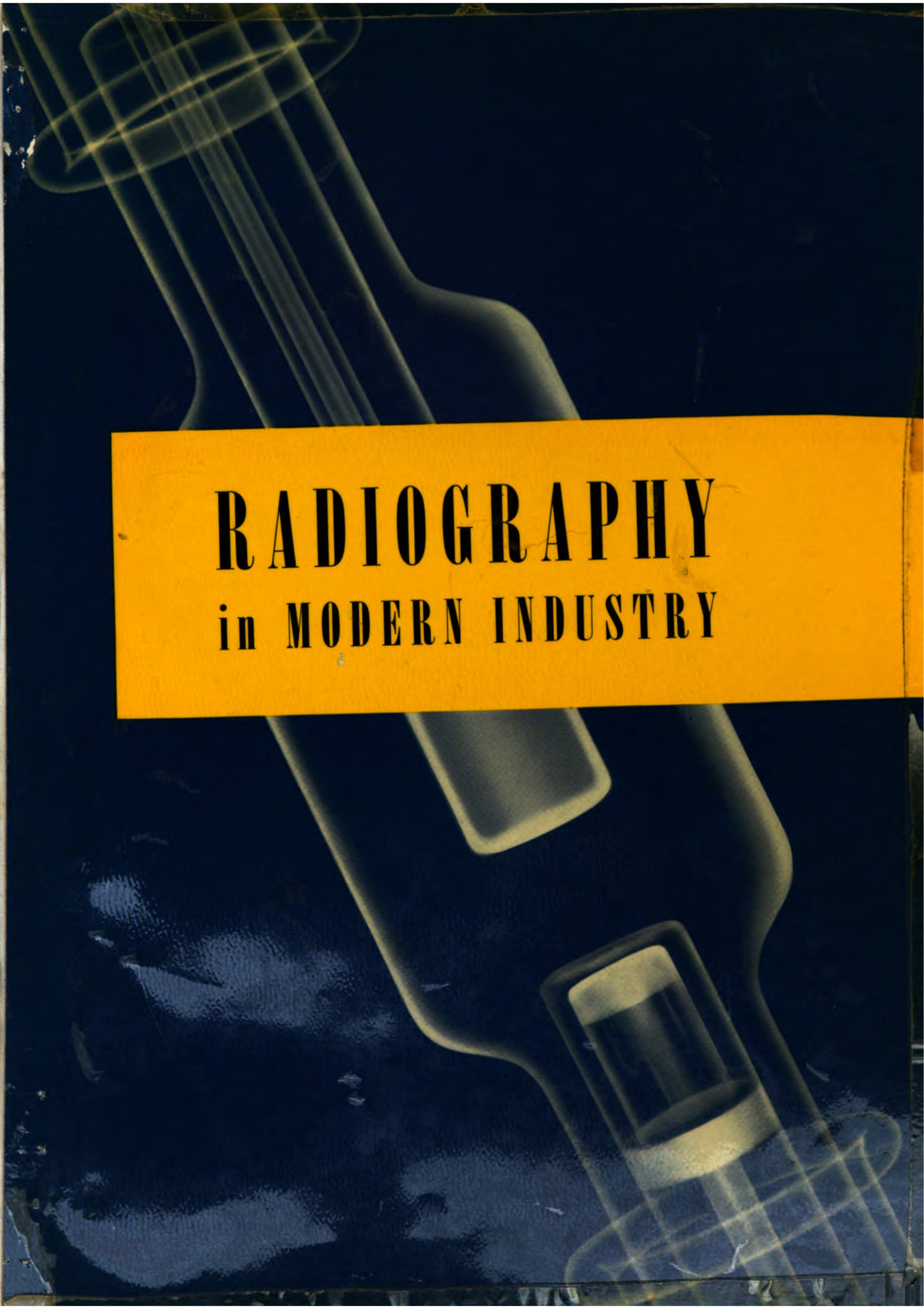

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RADIOGRAPHY
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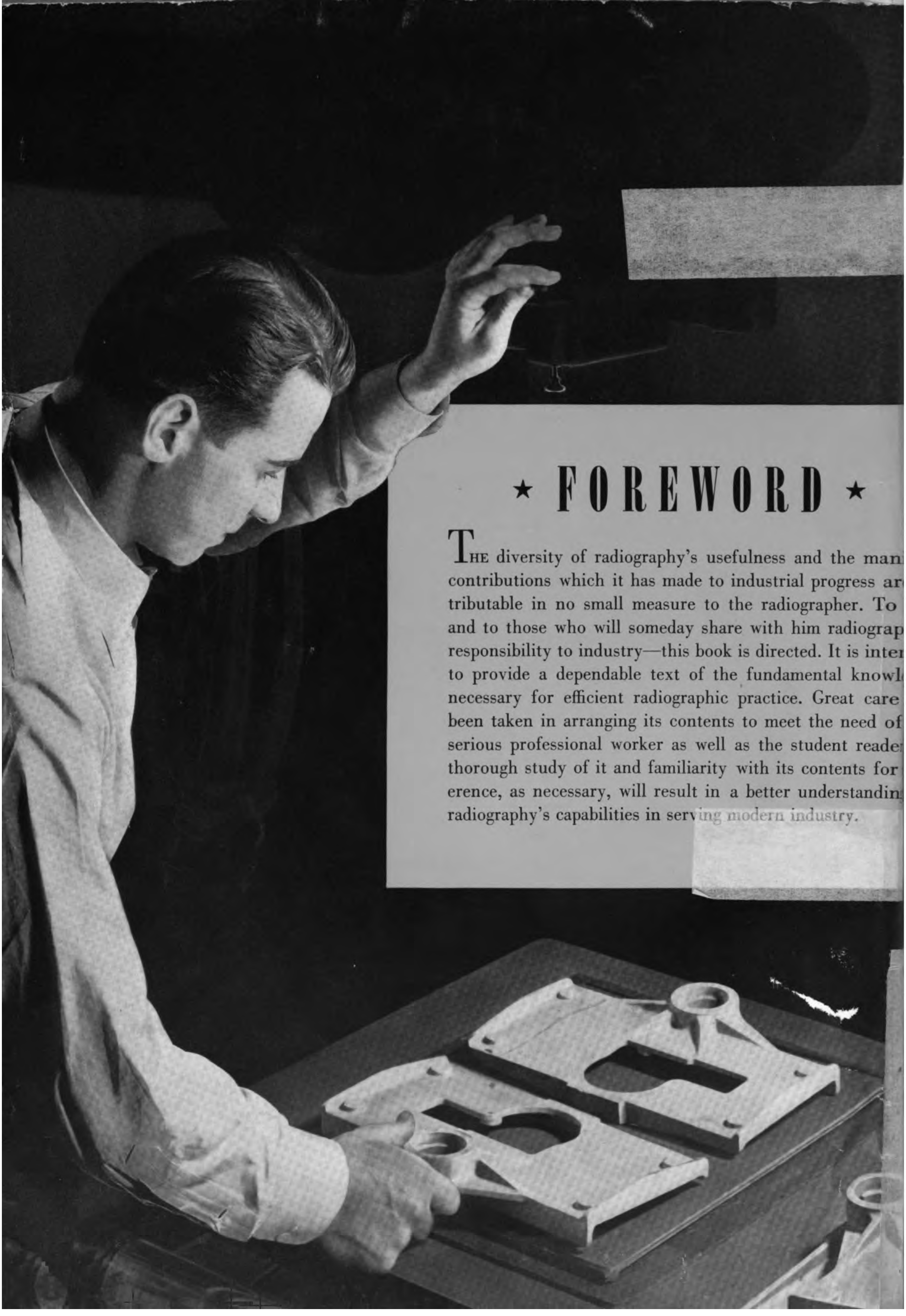

★ FOREWORD ★

THE diversity of radiography's usefulness and the man
contributions which it has made to industrial progress ar
tributable in no small measure to the radiographer. To
and to those who will someday share with him radiograp
responsibility to industry—this book is directed. It is inte
to provide a dependable text of the fundamental knowl
necessary for efficient radiographic practice. Great care
been taken in arranging its contents to meet the need of
serious professional worker as well as the student reade
thorough study of it and familiarity with its contents for
erence, as necessary, will result in a better understandin
radiography's capabilities in serving modern industry.

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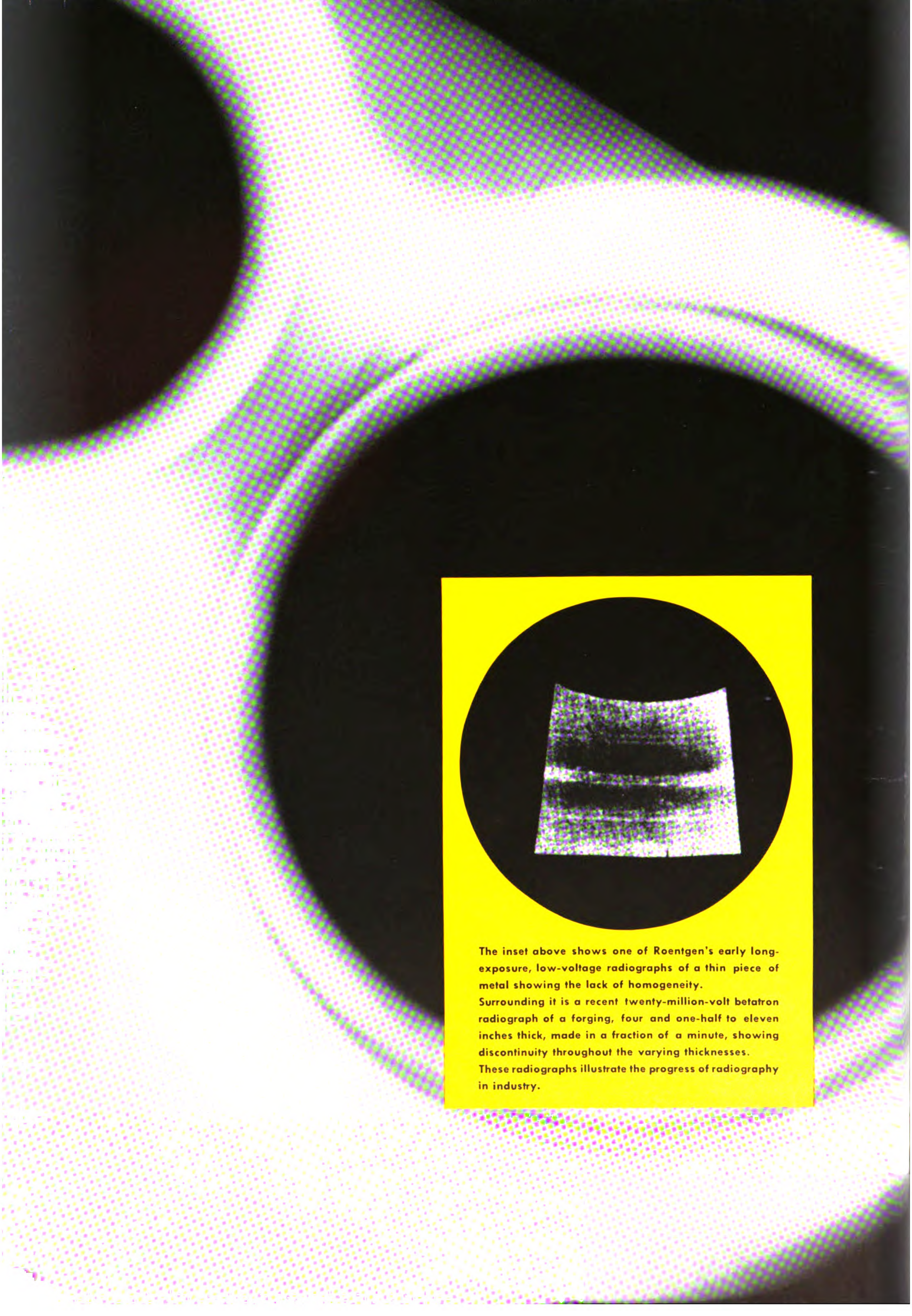


The inset above shows one of Roentgen's early long-exposure, low-voltage radiographs of a thin piece of metal showing the lack of homogeneity.

Surrounding it is a recent twenty-million-volt betatron radiograph of a forging, four and one-half to eleven inches thick, made in a fraction of a minute, showing discontinuity throughout the varying thicknesses.

These radiographs illustrate the progress of radiography in industry.

RADIOGRAPHY'S FUNCTION IN INDUSTRY

INSPECTION specifications designed to assure satisfactory performance of a product by determining the soundness of its internal structure, dependably and without damage, provided the impetus for the growth in the use of radiography by industry.

Because radiography provides a permanent, visible film record of the internal condition of a product, obtainable in no other way, it furnishes fundamental information helpful in judging soundness or unsoundness.

Industry quickly recognized the potential value of the information revealed by this film record, or radiograph. This evidence not only helped keep unsound parts from production lines before expensive machining or broken cutting tools exposed hidden defects; but, by showing the nature and location of irregularities, the radiograph indicated methods to correct them. As a result, industry was able to increase its acceptable yield from raw material processes considerably, as in casting, for example. Remarkable cost reductions in machining were also accomplished by allowing only known sound pieces on the production lines.

Engineers, ever alert to changes which mean lower cost and speedier production, found that, because radiography could assure soundness, it would enable substitution of lower cost materials and fabricating methods for costlier ones necessary where soundness was an estimated quality; for example, sound castings for some types of forgings, lightweight weldments for massive castings, speedy spot welding for slower riveting, etc.

Designers accustomed to using thicker sectional elements as a compensatory safety factor found that radiography, by assuring soundness, permitted safe reduction of much unnecessary weight. This saving in weight further reduced cost of materials—in many cases, permitting specification of less expensive ones.

Radiographs have been a great help in improving and controlling workmanship. As evidence of quality they have enhanced the reputation of many manufacturers for producing quality products.

The application of radiography to industry ranges from the need to examine one or several pieces occasionally to thousands hourly. The small manufacturer whose particular requirements make uneconomical the installation of x-ray facilities to meet his needs uses radium or the services of a professional x-ray laboratory in his area. Other manufacturers with greater needs use x-ray equipment built to meet their specific purpose. Many industrial plants use both x-ray and radium, and costs range from very modest rental fees for radium to an expenditure of many thousands of dollars for complete x-ray facilities. Many specialized pieces of equipment to meet specific requirements for speed and economy in operation have been installed.

Savings in manufacturing exceeding the cost of even the most expensive equipment, in as short a period of time as three months after installation, are not at all uncommon.

Spectacular reports have been made of the advantages offered by industrial radiography and new uses are being reported almost daily. Basically the reason for its economic usefulness is the fact that it provides a permanent, visible film record of the internal structure of an object without damaging it in any way.

Radiography's use by industry extends from basic operation to final assembly. Its job is to assure satisfactory performance, improve quality, and lower costs. Its record of accomplishment is as dependable as the information it provides. It is proving itself indispensable to designers, engineers, production men, inspectors, and to everyone in industry concerned with sound practices, dependable products, and lower costs.

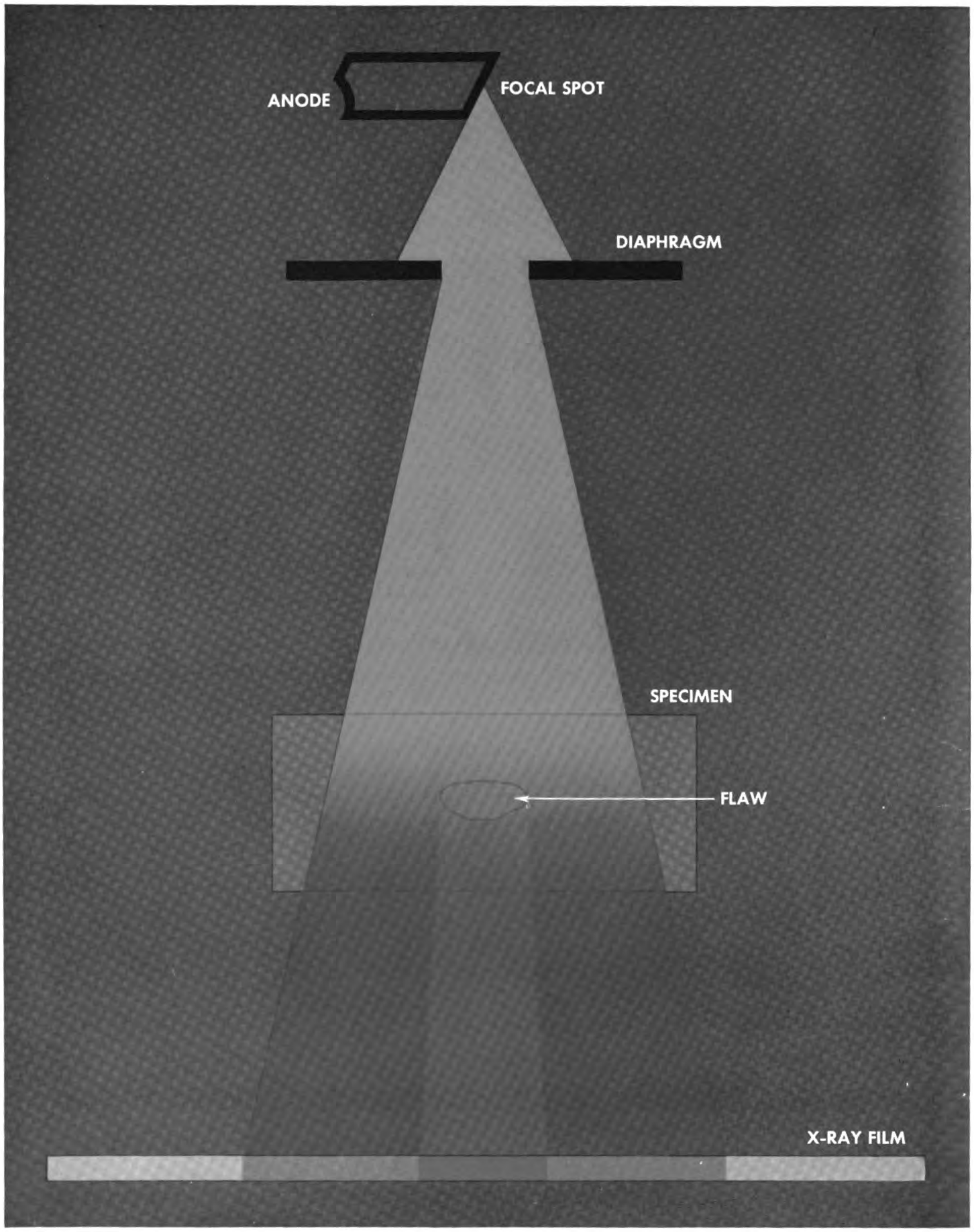


Fig. 1—Schematic diagram showing the fundamentals of a radiographic exposure. The dark region of the film represents the more penetrable part of the object, the light regions the more opaque.

THE RADIOGRAPHIC PROCESS

NATURE OF X-RAYS

X-RAYS are a form of radiant energy, like visible light. Their distinguishing feature is their extremely short wave length—only about 1/10,000 the length of the wave of visible light, or even less. It is this characteristic that is responsible for the x-rays' ability to penetrate materials which absorb or reflect ordinary light.

X-rays exhibit all of the properties of visible light, but in such a different degree as to modify greatly their practical behavior. For example, light is refracted by glass and, consequently, is capable of being focused by a lens in such instruments as cameras, microscopes, telescopes, and spectacles. X-rays are also refracted, but to such a very slight degree that the most refined experiments are required to detect this phenomenon. Hence, it is impossible to focus x-rays. It would be possible to illustrate the other similarities between x-rays and light but, for the most part, the effects produced are so different—particularly their penetration—that it is preferable to consider x-rays and gamma rays separately from other radiations. Figure 2 shows their location in the electromagnetic spectrum.

NATURE OF GAMMA RAYS

Gamma rays, which are emitted during the disintegration of radium, are very similar in their characteristics to x-rays but, as their wave length is short, they have great penetrating power.

MAKING A RADIOGRAPH

A *radiograph* is a photographic record produced by the passage of x-rays, or gamma rays, through an object onto a film. When film is exposed to x-rays, gamma rays, or light, an invisible change is produced in the film emulsion. The areas so exposed become dark when the film is immersed in a developing solution, the amount of darkening depending upon the degree of exposure. After development, the film is rinsed, preferably in a special bath, to stop development. The film is next put into a fixing bath which dissolves away the undarkened portions of the sensitive salt, and then is washed to remove the fixing chemicals.

The diagram in Figure 3 shows the essential features in the exposure of a radiograph. The focal spot is a small area in the x-ray tube from which the radiation emanates. In gamma radiography, it is the capsule containing the radium salt and its disintegration products which is the source of radiation. In either case the radiation proceeds in straight lines to the object; some of the rays pass through and others are absorbed—the amount transmitted depending on the nature of the material and its thickness. If the object is a steel casting, for example, and a void, which was formed by a gas bubble, exists, more radiation will pass through the section containing the void than through the surrounding area because the void results in a reduction of the total thickness of steel to be penetrated. A dark spot,

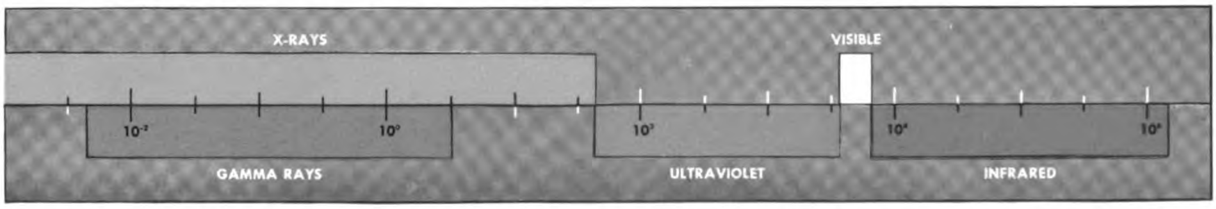


Fig. 2—Portion of the electromagnetic spectrum. Wave lengths are given in Angstrom units. (1Å = 10^{-8}cm. = 3.937 × 10^{-9} inch.)

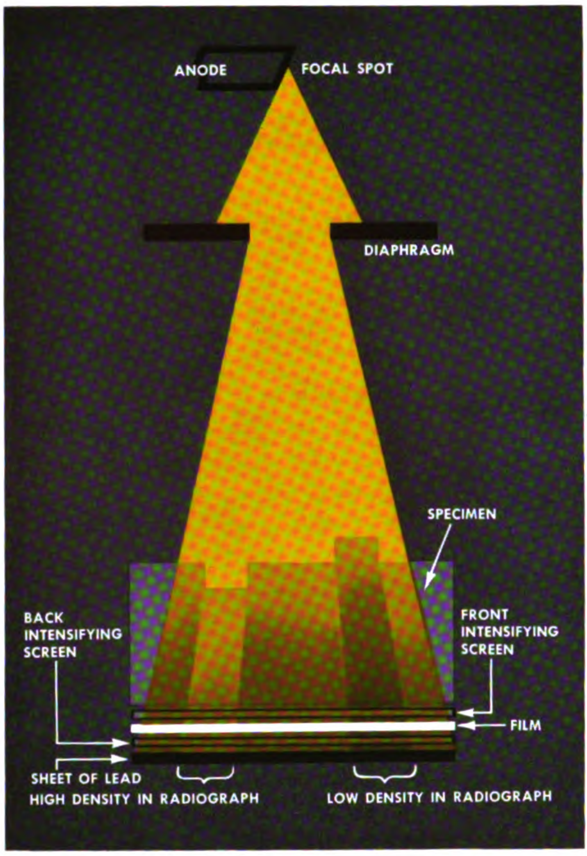

ANODE
FOCAL SPOT
DIAPHRAGM
SPECIMEN
BACK INTENSIFYING SCREEN
FRONT INTENSIFYING SCREEN
FILM
SHEET OF LEAD
HIGH DENSITY IN RADIOGRAPH
LOW DENSITY IN RADIOGRAPH

Fig. 3—Assembly for making an industrial radiograph.

corresponding to the projected position of the void, will therefore appear on the film when it is developed. Thus, a radiograph is a kind of shadow picture—the darker regions on the film representing the more penetrable parts of the object and the lighter regions the more opaque.

X-ray and other photographic films are sensitive to the direct action of the x-rays, but the photographic effect may be increased very appreciably and exposure time necessary decreased by the use of a fluorescent chemical, e.g., calcium tungstate, in contact with both sides of the film. Such a powdered chemical is mixed with a suitable binder and coated on cardboard to form an intensifying screen. Its action depends upon the fact that it converts some of the x-ray energy into ordinary visible light to which the film is very sensitive.

Lead foil may be used as an intensifying screen but its action is much less effective in reducing exposure time than the fluorescent chemical. Its principle of operation is different. Under the excitation of x-rays of short wave length, and gamma rays, it is a good emitter of electrons, which expose the sensitive film, thus increasing the total photographic effect. The decision as to the type of screen to be used—or whether a screen is to be used at all—depends upon a variety of circumstances which will be discussed in more detail later.

It is a property of *all materials* not only to absorb and transmit x-rays, in varying degrees, but also to *scatter* them in all directions. In radiography, the film receives scattered radiation from the object, the film holder, and any other material in the path of the primary x-ray beam. The effect is to diminish the contrast, detail, and clarity of the radiographic image. Lead foil, in contact with the film, lessens the relative effect of this longer wave length radiation. Under some circumstances, a filter of copper or lead, placed between the x-ray tube and the object, diminishes the effect of x-ray scatter upon the film. A lead mask, limiting the volume of matter exposed to the primary x-ray beam, may be helpful in lessening scatter. More detailed information on this subject is found in a later chapter.

Several special types of x-ray film have been designed for the radiography of materials. One type is intended primarily for use with calcium tungstate intensifying screens. Some types work best with lead screens, or without screens. Films are supplied in various degrees of contrast and grain characteristics. X-ray films are commonly coated with emulsion on both sides of the support—the superposition of the radiographic images of the two emulsion layers doubles the density and hence greatly increases the speed. Kodak makes four types of films expressly designed to meet the varied conditions encountered in industrial radiography. They are described in a later chapter as are two medical x-ray films which have occasional industrial use.

X-RAY GENERATING APPARATUS

PRODUCTION OF X-RAYS

X-RAYS are produced when electrons, traveling at high speed, collide with matter in any form. In the usual form of x-ray tube, an incandescent filament supplies the electrons, and thus forms the cathode, or negative electrode, of the tube. A high voltage applied to the tube drives the electrons to the anode, or target. The sudden stopping of these electrons in the surface of the target results in the generation of x-rays.

The design and spacing of the electrodes, and the degree of vacuum, are such that no electrical discharge between cathode and anode is possible until the filament of the cathode is heated.

Figure 4 is a schematic diagram of the essential parts of an x-ray tube. The filament is heated by a current of several amperes from a low voltage source, generally a small transformer. The *focusing cup* serves to concentrate the stream of electrons on a small area of the target, called the *focal spot*. This stream of electrons constitutes the *tube current*, and is measured in *milliamperes*.

The higher the temperature of the filament, the greater is its emission of electrons, and the larger the resulting tube current. The tube current is controlled, therefore, by some device which regulates the heating current supplied to the filament. This is usually accomplished by a choke coil in the primary circuit of the filament transformer. Other conditions remaining the same, the x-ray output is proportional to the tube current.

Most of the energy applied to the tube is transformed into heat at the focal spot, only a small portion being transformed into x-rays. The high concentration of heat in a small area imposes a severe burden on the materials and design of the anode. The efficiency of the target material in the production of x-rays is proportional to its atomic number. The high atomic number of tungsten, in combination with its high melting point, makes it the most suitable material for the target of an x-ray tube. Circulation of water or oil in the interior of the anode is an effective method of carrying away the heat. In the absence of provision for liquid cooling, the use of copper for the main body of the anode provides high heat conductivity, while radiating fins on the end of the anode outside the tube transfer the heat to the surrounding oil or air. The focal spot should be as small as conditions permit,

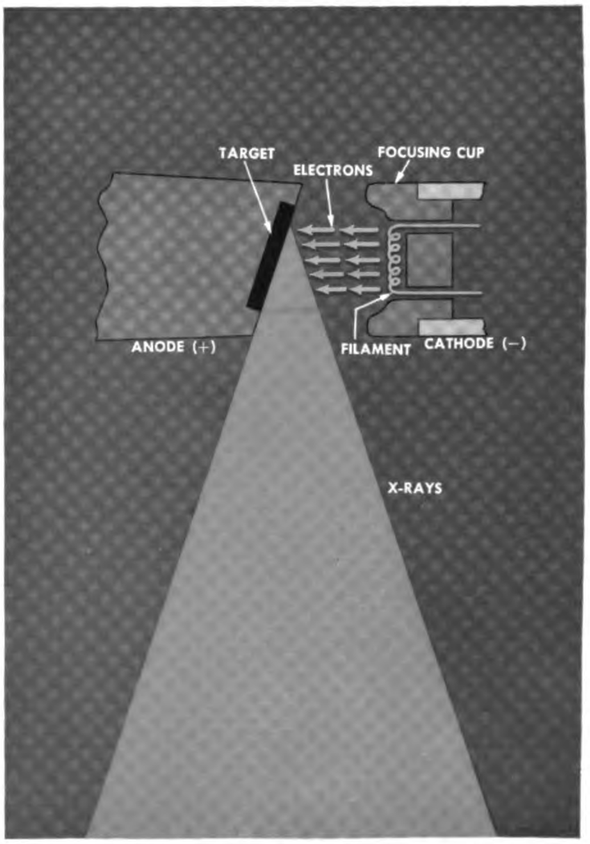


Fig. 4—Schematic diagram of an x-ray tube.

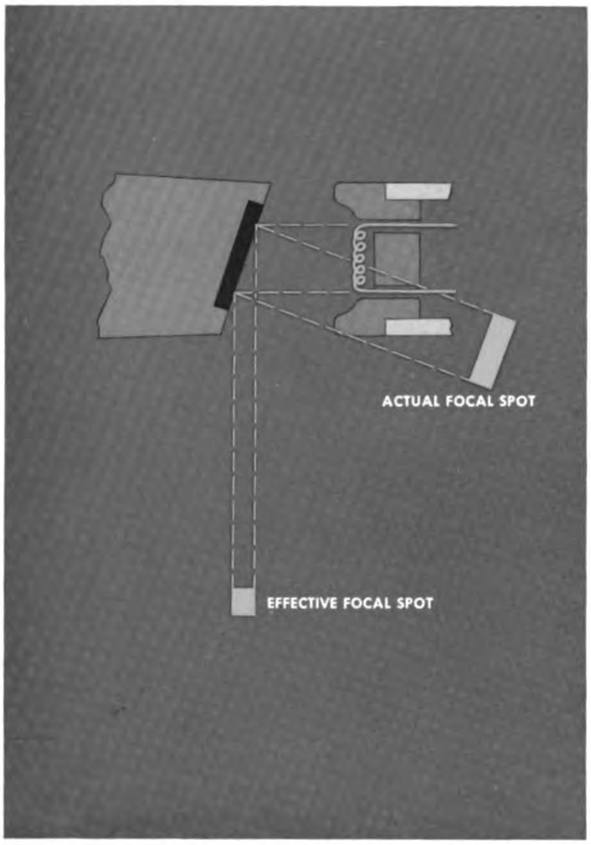


Fig. 5—Diagram of a line-focus tube depicting relation between actual focal spot (area of bombardment) and effective focal spot, as projected from a 20° anode.

in order to secure the sharpest possible definition in the radiographic image. However, the smaller the focal spot, the less energy it will withstand without damage. Manufacturers of x-ray tubes furnish data in the form of charts indicating the kilovoltages and milliamperages that may be safely applied at various exposure times, and the life of any tube will be prolonged considerably if it is always operated within the rated capacity.

A focal spot of small effective size, though the actual focal area on the anode face may be fairly large, is provided by the principle of line focus, illustrated in Figure 5. By making the angle between anode face and central ray small, usually 20 degrees, the effective area of the spot is only a fraction of its actual area. With the focal area in the form of a long rectangle, as shown, the projected area, in the direction of the central ray, is square.

As will be seen later, different voltages are applied to the x-ray tube to meet the demands of various classes of radiographic work. The higher the voltage, the greater the speed of the electrons striking the focal spot. The result is a decrease in wave length of the x-rays emitted and an increase in their penetrating power and intensity. It is to be noted that x-rays produced, for example, at 200 kilovolts contain all of the wave lengths that would be produced at 100 kilovolts, and with greater intensity. In addition, the 200-kilovolt x-rays include some shorter wave lengths which do not exist in the 100-kilovolt spectrum at all. The higher voltage x-rays are used for the penetration of thicker and heavier materials.

X-ray generating apparatus (see Figure 6) comprises, aside from the x-ray tube, the following principal components: a high-voltage transformer; an autotransformer; a rectifier; and a power supply for the x-ray tube filament.

A transformer makes it possible to change the voltage of an alternating electric current. In the simplest form, it consists of two coils of insulated

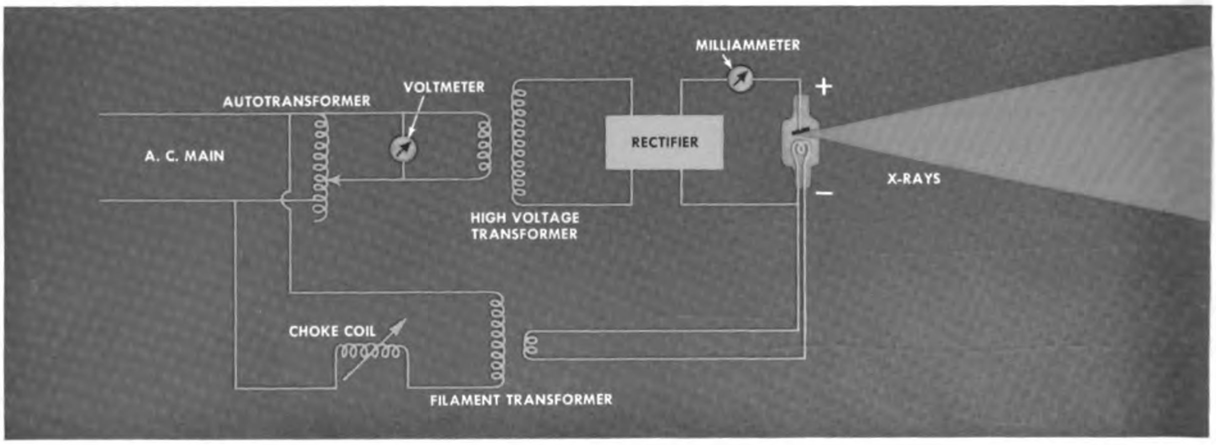


Fig. 6—Principal electrical features of an x-ray machine.

wire wound on an iron core. The coil connected to the source of alternating current is called the *primary* winding, the other the *secondary* winding. The voltages in the two coils are directly proportional to the numbers of turns, assuming 100 per cent efficiency. Thus, if the primary has few turns, say 100, and the secondary has very many, say 100,000, the voltage in the secondary is 1000 times as high as that in the primary. At the same time the current in the coils is decreased in the same proportion as the voltage is increased. In the example given, therefore, the current in the secondary is only 1/1000 that in the primary. It is a *step-up* transformer of this type that is used to supply the high voltage to the x-ray tube.

The transformer laws may be stated mathematically as follows:

$$\frac{n_1}{n_2} = \frac{V_1}{V_2}$$

$$V_1I_1 = V_2I_2$$

where n_1 and n_2 are the number of turns in the primary and secondary, respectively. V_1 and V_2 are the effective voltages and I_1 and I_2 the effective currents in the primary and secondary windings, respectively. In other words, the power input is equal to the power output. This equation assumes, of course, that the transformer is 100 per cent efficient. Actually it is not possible to obtain quite as much power on the secondary side of the transformer as is applied to the primary side. (In discussing x-ray technics, the voltage applied to the x-ray tube is usually expressed in terms of peak kilovolts, i.e., the kilovoltage of the highest points of the curves of Figure 7.

An autotransformer is a special type of transformer in which the output voltage is easily varied over a limited range. In an x-ray generator, the autotransformer permits the adjustment of the primary voltage applied to the step-up transformer, and hence of the high voltage applied to the x-ray tube.

The type of voltage *wave form* supplied by the high-voltage transformer is shown in Figure 7A and consists of alternating pulses, first in one direction and then in the other. Generally speaking, this is not suitable for direct application to the x-ray tube. The high voltage is therefore supplied to a unit called a *rectifier* which converts the pulses into the unidirectional form illustrated in Figure 7B. Another type of rectifier may convert the wave form to that of Figure 7C, but the general idea is the same in both cases, i. e., unidirectional voltage is supplied to the x-ray tube. It is to be noted, however, that recent developments of industrial x-ray tubes have made possible the direct application of the high-voltage wave form of Figure 7A to the x-ray tube, which then acts as its own rectifier. Many different high-voltage wave forms are possible, depending upon the design of the x-ray machine and its installation. Figure 7 shows idealized wave forms difficult to achieve in practical high voltage equipment. Departures from these forms may vary in different x-ray installations. Since x-ray output depends upon the entire wave form, this accounts for the variation in radiographic results which may be obtained from two different x-ray machines operated at the same value of peak kilovoltage. No attempt is made here to discuss in detail the various forms of electrical generating equipment. The essential fact is that high voltage is required at the terminals of the x-ray tube.

In developing suitable exposure technics, it is important to know the voltage applied to the x-ray tube. It is common practice for manufacturers of

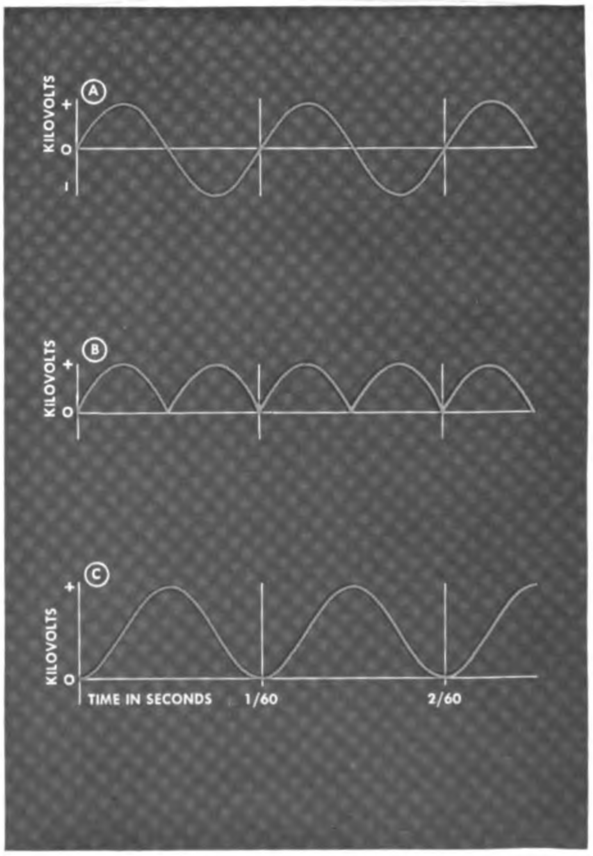


Fig. 7—Types of x-ray machine voltage wave forms.

x-ray equipment to calibrate their machines at the factory so that the operator may know the voltage across the x-ray tube from the readings of the voltmeter connected to the primary of the high-voltage transformer. Furthermore, in modern x-ray generators, the tube is entirely enclosed within a shockproof container, so that the tube terminals are not accessible for calibration purposes.

The power supply for the x-ray tube filament consists of a *step-down* transformer. A choke coil serves for adjustment of the current supplied to the filament.

APPLICATIONS OF VARIOUS TYPES OF APPARATUS

The various x-ray machines commercially available may be roughly classified according to their maximum voltage. The choice among the various classes will depend upon the type of work to be done. The tabulation below lists voltage ranges of typical x-ray machines and their applications. These ranges are approximate, since the exact voltage limits of the machines vary from one manufacturer to another.

The x-ray machines listed below may be either fixed or mobile, depending on the specific uses for which they are intended. When the material to be radiographed is portable, the x-ray machine is usually permanently located in a room protected against the escape of x-radiation. The x-ray tube itself is frequently mounted on a stand allowing considerable freedom of movement. For the examination of objects which are fixed, or movable only with great difficulty, mobile x-ray machines may be used. These machines have the x-ray tube, high-voltage generator, and control stand all mounted on a truck which may be rolled to any part of the plant. Semi-automatic machines have been designed for the radiography of large numbers of relatively small parts on a "production line" basis. The radiation protection is such that an operator may safely work alongside these machines. During the course of an exposure, he may arrange the parts to be radiographed at the next exposure, and remove those just radiographed, with an obvious saving in time.

Gamma rays, because of their extremely short wave length, have great penetrating power. They may be used to radiograph steel sections as thick as 8 inches, or the equivalent. A further advantage of gamma rays is the simplicity of the apparatus used and the compactness of the capsule which contains the radiation source. This facilitates the examination of pipe, pressure vessels, and other assemblies, where access to the interior may be difficult.

TYPICAL X-RAY MACHINES AND THEIR APPLICATIONS

Maximum Voltage (KvP)	Screens	Applications and Approximate Practical Thickness Limits
50	None	Extremely thin metallic sections. Wood, plastics, biological specimens, etc.
150	None or lead foil	Light alloys, 4½-inch aluminum or equivalent (see page 15). 1-inch steel, or equivalent.
	Calcium tungstate	1½-inch steel, or equivalent. (See page 15).
250	Lead foil	2-inch steel, or equivalent.
	Calcium tungstate	3-inch steel, or equivalent.
400	Lead foil	3-inch steel, or equivalent.
	Calcium tungstate	4-inch steel, or equivalent.
1000	Lead foil	5-inch steel, or equivalent.
2000	Lead foil	8-inch steel, or equivalent.

GEOMETRIC PRINCIPLES

A RADIOGRAPH is a shadow picture of an object that has been placed in the path of an x-ray beam, between the tube anode and the film or between the source of gamma radiation and the film. It naturally follows, therefore, that the appearance of an image thus recorded is materially influenced by the relative positions of the object and the film and by the direction of the beam. For these reasons, thorough familiarity with the elementary principles of shadow formation is important to those making and interpreting radiographs.

GENERAL PRINCIPLES

Since x-rays and gamma rays obey the common laws of light, their shadow formation may be explained in a simple manner in terms of light. It should be borne in mind that the analogy between light and x-rays or gamma rays is not perfect, since all objects are, to a greater or lesser degree, transparent to x-rays and since scattering presents greater problems in radiography than in optics. However, the same geometric laws of shadow formation hold for both radiations.

Suppose, as in Figure 8A, that there is light from a point (L) falling on a white card (C), and an opaque object (O) is interposed between the light source and the card. A shadow of the object will be formed on the surface of the card.

This shadow cast by the object will naturally show some *enlargement* because the object is not in contact with the card; the *degree of enlargement* will vary according to the relative distances of the object from the card and from the light source. The *form of the shadow* also may differ according to the angle which the object makes with the incident light rays. Deviations from the *true shape* of the object as exhibited in its shadow image are called *distortion.* For present purposes, however, the law governing the size of the shadow and the size of the object may be stated in simple terms in the following manner:

The diameter of the shadow is to the diameter of the object as the distance of the light from the card is to the distance of the light from the object.

The degree of sharpness of any shadow depends upon the size of the source of light and upon the position of the object between the light and the card--whether nearer to or farther from one or the other. The shadows cast when the source of light is not a point but a small area are not perfectly sharp (Figures 8B, C, D) because *each point* in the source of light casts its own shadow of the object, and all of these overlapping shadows are slightly out of register, or displaced from each other, thereby producing an ill-defined image.

Figure 8 (A to F) shows the effects of changing the size of the source and of changing the relative positions of source, object, and card. From an examination of these drawings, it will be seen that the following conditions must be fulfilled to produce the sharpest, truest shadow of the object:

1. The source of light should be small, i. e., as nearly a point as can be obtained. Compare Figures 8A and C.
2. The source of light should be as far from the object as practicable. Compare Figures 8B and C.
3. The recording surface should be as close to the object as possible. Compare Figures 8B and D.
4. The light rays should be directed perpendicularly to the recording surface. See Figures 8A and E.
5. The plane of the object and the plane of the recording surface should be parallel. Compare Figures 8A and F.

RADIOGRAPHIC SHADOWS

The basic principles of shadow formation must be given primary consideration in order to assure satisfactory sharpness in the radiographic image and essential freedom from distortion. A certain

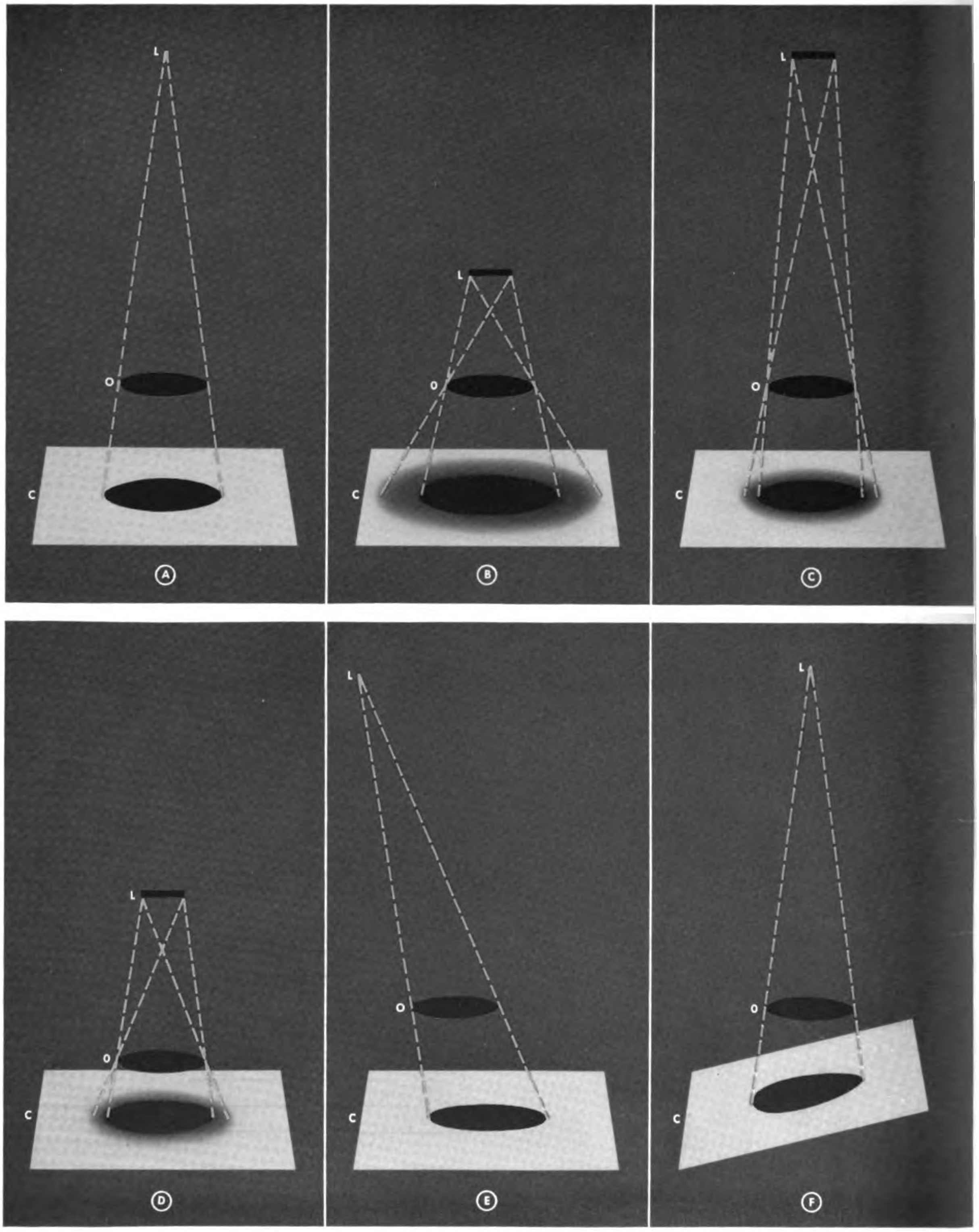


Fig. 8—Illustrating the general geometric principles of shadow formation. In Figures 8A, B, C, and D, enlargement alone takes place. In Figures 8E and F, both enlargement and distortion take place.

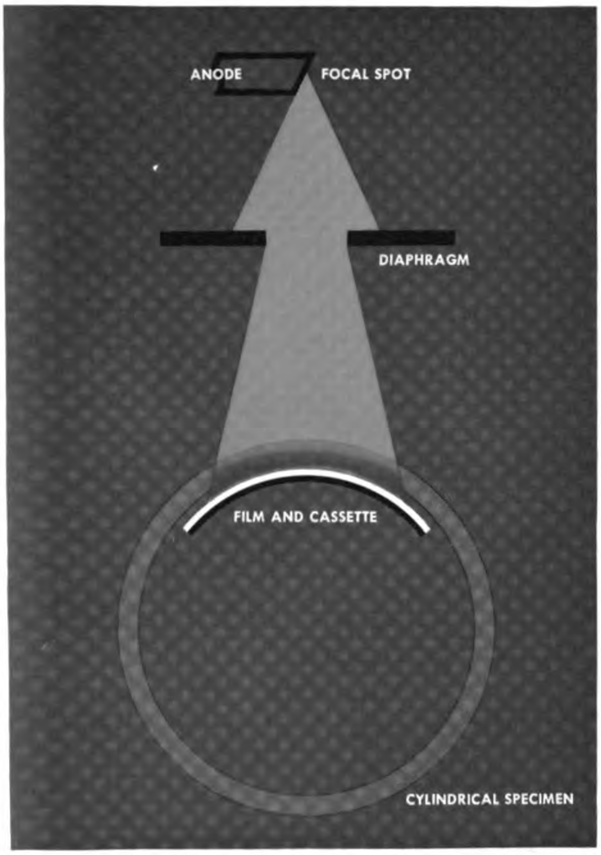


Fig. 9—A suitably curved cassette is better than a flat one for curved objects, because the film should be as close to the object as possible for good definition.

degree of distortion naturally will exist in every radiograph because of the fact that some parts will always be farther from the film than others, the greatest magnification being evident in the image of those parts at the greatest distance from the recording surface. Distortion cannot be eliminated entirely, but, by the use of an appropriate focus-film distance, it can be lessened to a point where it will not be objectionable.

1. The x-rays should proceed from as small a focal spot as other considerations will allow, for there is a definite relationship between the focal spot size of the x-ray tube and the *definition* in the radiograph. A broad-focus tube, although capable of withstanding high energies, does not permit the delineation of as much detail as a fine-focus tube. Long focus-film distances will aid in showing detail when employing a broad-focus tube, but it is generally considered advantageous to use the smallest focal spot permissible for the exposures required.

2. The distance between the anode and the material examined should always be as great as is practical. Maximum focus-film distances should be used in the radiography of thick materials, to minimize the natural tendency for the structures that are farthest from the film to be less sharply recorded than those nearer to it. At maximum distances, definition is improved and the image is more nearly the actual size of the object.

3. The film should be as close as possible to the object being radiographed. (See Figure 9.) In practice, the film—in its cassette or exposure holder—is placed in contact with the object, except when grid diaphragms are employed.

4. The central ray should be as nearly perpendicular to the film as possible to minimize distortion.

5. As far as the shape of the specimen will allow, the plane of maximum interest should be parallel to the film.

PINHOLE PROJECTION OF FOCAL SPOT

Since the dimensions of the radiation source have considerable effect on the sharpness of shadows, it is frequently desirable to determine the shape and size of the x-ray tube focal spot. This may easily be accomplished by the method of pinhole

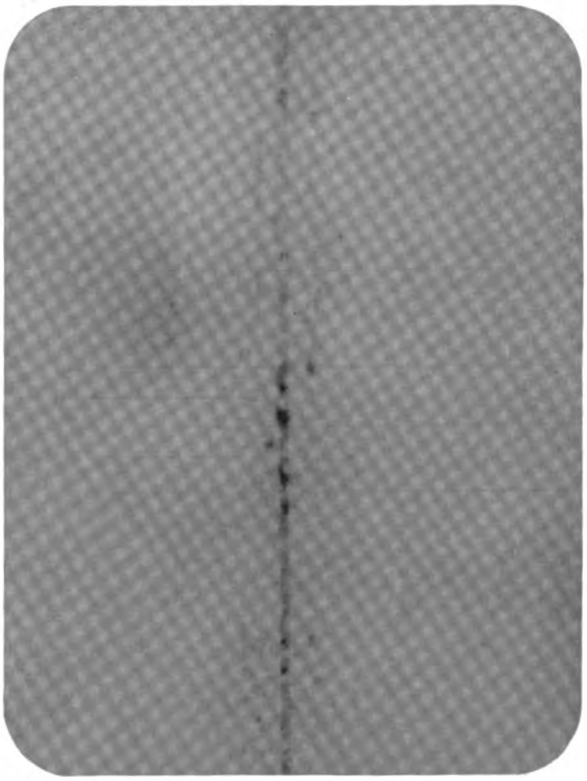


Fig. 10—Radiograph of defective weld in steel plate.

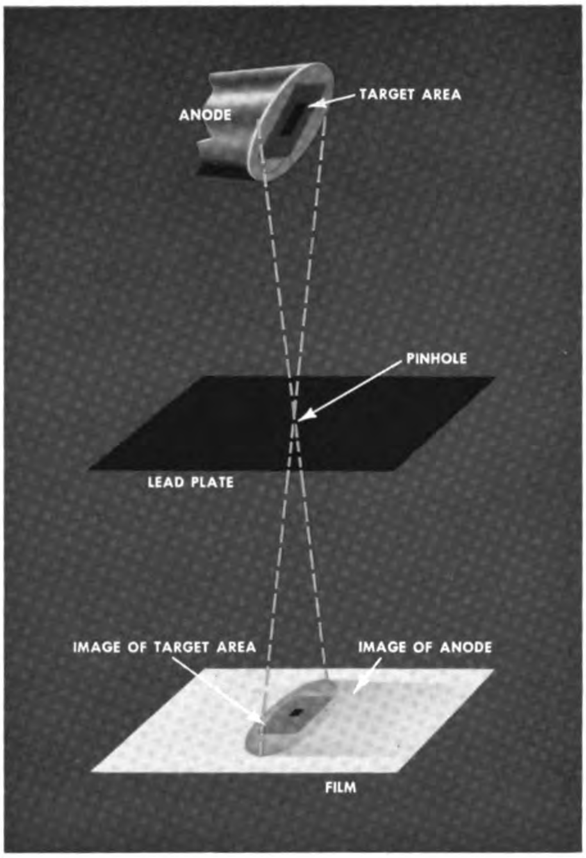


Fig. 11—Schematic diagram showing the production of a pinhole picture of an x-ray tube focal spot.

radiography, which is identical in principle with the pinhole camera. A thin lead plate containing a small hole is placed exactly midway between the focal spot and film, and lead shielding is so arranged that no x-rays reach the film except those passing through the pinhole. There results on the developed film an image which is equal in size and shape to the effective focal spot.

A focus-film distance of 24 inches is usually convenient. Of course, the time of exposure will be much greater than would be required for exposing the film without the pinhole plate because so little radiation can get through such a small aperture. The image can be perfect only if the hole is a geometrical *point*, but a needle or a No. 60 drill will make a hole small enough for practical purposes.

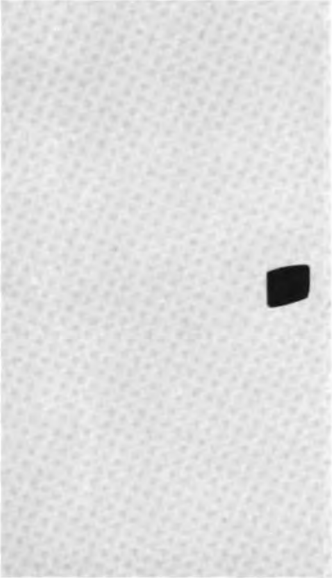
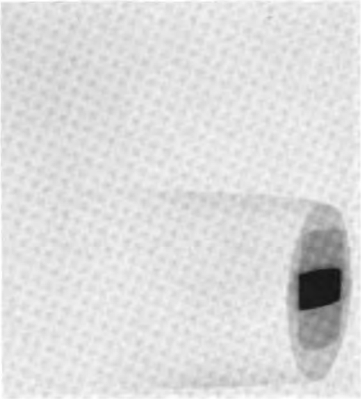


Fig. 12—Pinhole pictures of the focal spot of an x-ray tube. Shorter exposure (top) shows only focal spot. Longer exposure (lower) shows, as well as the focal spot, some detail of tungsten button and copper anode stem. The x-ray images of these parts result from their bombardment by stray electrons.



FACTORS GOVERNING EXPOSURE

Generally speaking, the density of any radiographic image depends upon the amount of radiation absorbed by the sensitive emulsion of the film. This amount of radiation in turn depends upon several factors: the total amount of radiation emitted by the x-ray tube; the amount of radiation reaching the specimen; the proportion of this radiation which penetrates the specimen; and the intensifying action of screens, if they are used. These factors will be discussed in order.

The total amount of radiation emitted by an x-ray tube depends upon the tube current (milliamperage), the kilovoltage, and the total time the tube is energized.

When other operating conditions are held constant, a change in milliamperage causes a change in the *intensity* of the radiation emitted, the intensity being approximately proportional to the milliamperage. If the voltage wave form of an x-ray machine did not vary with load, this proportionality would be exact. In normal industrial radiographic practice the variation from exact proportionality is not serious and may usually be ignored.

Figure 13 shows spectral emission curves for an x-ray tube operated at two different currents, the higher being twice the lower. Therefore, *each wave length* is twice as intense in one beam as in the other. Note that no wave lengths are present in one beam that are not present in the other. Hence, there is no change in x-ray quality, or penetrating power.

As would be expected, the total amount of radiation emitted by an x-ray tube operating at a certain kilovoltage and milliamperage is directly proportional to the time the tube is energized.

Since the x-ray output is directly proportional to both milliamperage and time, it is directly proportional to their product. (This product is referred to as the "exposure.") Algebraically, this may be

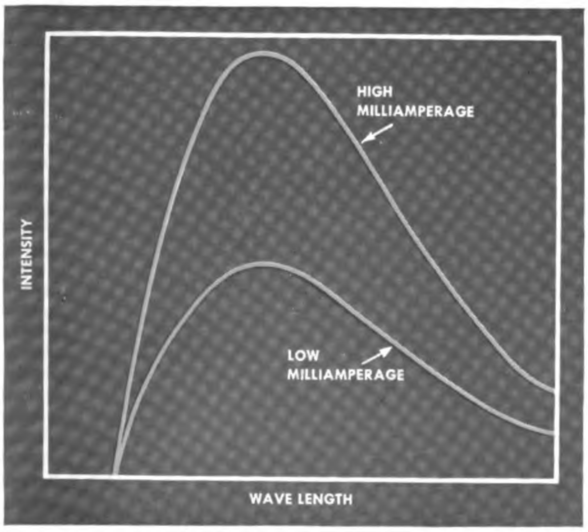


Fig. 13—Curves illustrating the effect of change of milliamperage on the intensity of an x-ray beam. (After Ulrey)

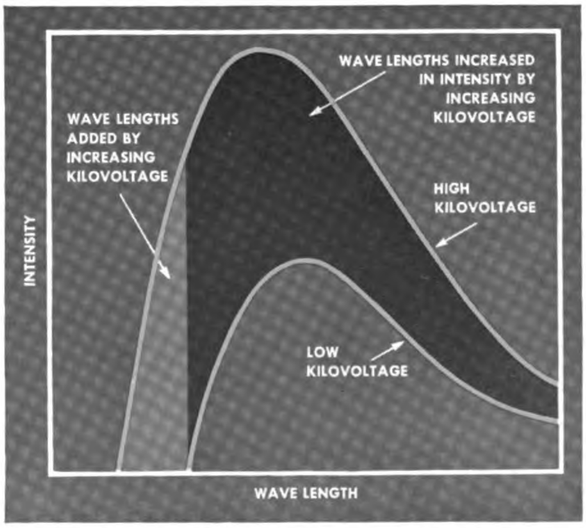


Fig. 14—Curves illustrating the effect of change of kilovoltage on composition and intensity of an x-ray beam. (After Ulrey)

stated, E = Mt, where E is the exposure, M the tube current, and t the exposure time. Hence, the amount of radiation will remain constant if the exposure remains constant, no matter how the individual factors of tube current and exposure time are varied. This permits specifying x-ray exposures in terms of milliampere-minutes or milliampere-seconds, without stating the specific values of tube current and time.

The kilovoltage applied to the x-ray tube affects not only the quality but also the intensity of the beam. As the kilovoltage is raised, x-rays of shorter wave length, and hence of more penetrating power, are produced. Figure 14 shows spectral emission curves for an x-ray tube operated at the same milliamperage but at two different kilovoltages. It is to be noted that, in the higher kilovoltage beam, there are some shorter wave lengths which are absent from the lower kilovoltage beam. Further, all wave lengths present in the lower kilovoltage beam are present in the more penetrating beam, and in greater amount. Thus, raising the kilovoltage not only increases the penetration, but also increases, sometimes to a great extent, the intensity.

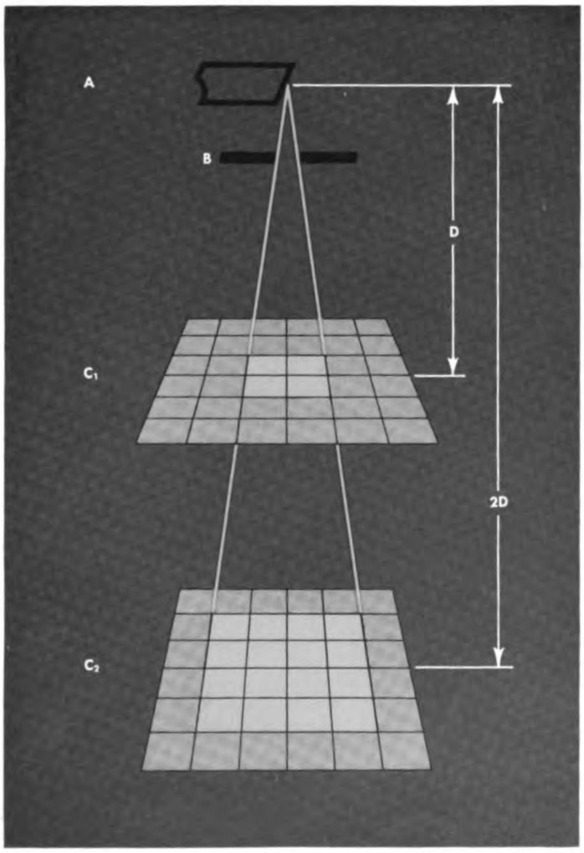


Fig. 15—Schematic diagram illustrating the inverse square law.

When the x-ray tube output is held constant, the x-ray intensity reaching the specimen is governed by the distance between the x-ray tube and the specimen, varying inversely with the square of this distance. Since x-rays conform to the laws of light, they diverge when they are emitted from the anode, and cover an increasingly larger area with lessened intensity as they travel from their source. This principle is illustrated by Figure 15. In this example it is assumed that the intensity of the x-rays emitted at the anode (A) remains constant, and that the x-rays passing through the aperture (B) cover an area of 4 square inches on reaching the recording surface (C_1) which is 12 inches (D) from (A). Then, when the recording surface (C_1) is moved 12 inches farther from the anode, to (C_2), so that the distance between (A) and (C_2) is 24 inches (2D), or twice the distance between (A) and (C_1), the x-rays will cover 16 square inches—an area 4 times as great as that at (C_1). It follows, therefore, that the radiation *per square inch* on the surface at (C_2) is only one quarter that at the level (C_1). Thus, the exposure that would be adequate at (C_1) must be increased 4 times in order to produce at (C_2) a radiograph of equal density. In practice this may be done (1) by increasing the time or (2) by increasing the milliamperage.

This inverse square law may be stated algebraically as follows:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$

where I_1 and I_2 are the intensities at distances d_1 and d_2 respectively.

If industrial radiography were done with monochromatic radiation, that is, with an x-ray beam containing but a single wave length, and if there were no scattering, the laws of absorption of x-rays by matter could be stated mathematically with great exactness. However, since a broad band of wave lengths is used and since considerable scattered radiation reaches the film, the laws can be given only in a general way.

The x-ray absorption of a specimen depends upon its thickness, its density, and, most important of all, upon the atomic nature of the material. It is obvious that of two specimens of similar composition, the thicker or the more dense will absorb the more radiation, necessitating an increase in kilovoltage or exposure, or both, to produce the same photo-

APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS OF SEVERAL METALS

Metal	50 KvP	100 KvP	150 KvP	200 KvP	1000 KvP	Gamma rays
Aluminum	1.0	1.0				
Magnesium	.6	.6				
24 ST Alloy	1.4	1.2				
Steel		22	1.0	1.0	1.0	1.0
18-8 Stainless Steel			1.0	1.0		
Copper			1.5	1.4		
Zinc			1.4	1.3		
"Brass"*			1.4*	1.3*	1.2*	1.1*
Lead			12	12	5	2.3

Aluminum is taken as the standard metal at 50 KvP and 100 KvP, and steel at the higher voltages. The thickness of another metal is multiplied by the corresponding factor to obtain the approximate equivalent thickness of the standard metal. The exposure applying to this thickness of the standard metal is used.

Example: To radiograph 0.5 inch of copper at 200 KvP, multiply 0.5 inch by the factor 1.4, obtaining an equivalent thickness of 0.7 inch of steel. Therefore, give the exposure required for 0.7 inch of steel.

*Tin or lead alloyed in the brass will increase these factors.

graphic result. However, the atomic elements in a specimen usually exert a far greater effect upon x-ray absorption than either the thickness or the density. For example, lead is about 1½ times as dense as ordinary steel, but, at 200 kilovolts, 0.1 inch of lead absorbs as much as 1.2 inches of steel. Brass is only about 1.1 times as dense as steel, yet, at 150 kilovolts peak, the same exposure is required for 0.25 inches of brass as for 0.35 inches of steel. A table of radiographic equivalents is given above. It will be noted from this table that the relative absorptions of different materials are not constant, but change with kilovoltage, and that, as the kilovoltage increases, the differences between all materials tend to become less.

The kilovoltage governs the penetrating power of an x-ray beam, and hence governs the intensity of the radiation passing through the specimen. It is not possible, however, to specify a simple relation between kilovoltage and x-ray intensity because such factors as the thickness and kind of material radiographed, the characteristics of the x-ray generating apparatus, and whether the film is used alone or with intensifying screens, exert a considerable influence on this relationship. The following example illustrates this point:

Data from a given exposure chart indicate that radiographs of equal density can be made of ¼-inch steel with either of the following sets of exposure conditions:

80 kilovolts peak, 35 milliampere-minutes
120 " " 1.5 " "

Thus, in this case, a 50 per cent increase in kilovoltage results in a *23-fold* increase in effective x-ray intensity.

Two-inch aluminum may also be radiographed at these two kilovoltages. Equal densities will result with the following exposure relations:

80 kilovolts peak, 17 milliampere-minutes
120 " " 2.4 " "

In this case, the same increase in kilovoltage results in an increase of x-ray intensity of only 7 *times.* Many examples can be found to illustrate the extreme variability of the effect of kilovoltage on x-ray intensity.

Combining the factors of kilovoltage, milliamperage, time and distance, the radiographic energy—the photographically effective energy reaching the film—may be stated as follows:

Radiographic energy =

$$\frac{\underset{\text{(kilovolts)}}{\text{Voltage}^{Y}} \times \underset{\text{(milliamperes)}}{\text{Current}} \times \underset{\text{(minutes or seconds)}}{\text{Time}}}{\text{Distance}^{2}\ \text{(inches or centimeters)}}$$

The exponent (Y) of the voltage in this formula may vary considerably with the conditions under which the exposure is made.

The quantity $\dfrac{\text{Current} \times \text{Time}}{\text{Distance}^{2}}$ is known as the "exposure factor," and radiographic technics are sometimes given in terms of kilovoltage and exposure factor. In such a case, it is merely necessary to multiply the exposure factor by the square of the distance to be used in order to find the milliampere-seconds or minutes required.

In using radium or other radioactive materials, the intensity of the source may be expressed in milligrams or in millicuries, respectively, and the milligram or millicurie values merely substituted for the milliamperage. Since gamma-ray exposures are fairly long, they are commonly expressed in milligram- or millicurie-hours. It may be noted that the quality (wave lengths) of gamma rays from radium remains fixed so that there is nothing to correspond to the variable kilovoltage factor of x-ray exposures.

The final factor governing the photographic density of the radiograph is the intensifying action of the screens used. Intensifying screens and lead foil screens are fully discussed in the chapter on Radiographic Screens, page 19. It will suffice to state here that x-rays cause calcium tungstate intensifying screens to emit light which materially lessens the exposure necessary to produce a given density. Lead foil screens emit electrons under the action of x-rays. The photographic effect of these electrons may permit a shorter exposure than would be required without lead screens.

DETERMINATION OF SPECIFIC EXPOSURE FACTORS

The focus-film distance is easy to establish by actual measurement; the milliamperage may be conveniently determined by the milliammeter supplied with the x-ray machine; and the exposure time may be accurately controlled by a good time-switch. The tube voltage, however, is difficult and inconvenient to measure accurately. Furthermore, individual designs of machines differ widely, and may give x-ray outputs of different quality and intensity even when operated at the same value of peak kilovoltage.

Consequently, while specified exposure technics may be duplicated satisfactorily in the factors of focus-film distance, milliamperage, and exposure time, one apparatus may differ materially from another in the kilovoltage setting necessary to produce the same radiographic density. Because of this fact, the kilovoltage setting for a given technic should be determined by trial on each x-ray generator. In the preliminary tests, published exposure charts may be followed as an approximate guide. It is customary for equipment manufacturers to calibrate x-ray machines at the factory and to furnish suitable exposure charts. For the unusual problems that arise, it is desirable to record in a logbook all of the data on exposure and technics. In this way the operator will soon build up a source of information that will make him more and more competent to deal with difficult situations.

For developing trial exposures, freshly prepared developer solution at a temperature of 68° F. (20° C.), or as near thereto as possible, should always be used. By employing a *standardized processing procedure* (see page 68), any variation in the quality of the radiographs may then be attributed to the exposure. This method obviates many of the variable factors common to radiographic work.

Since an increase of kilovoltage produces a marked increase in x-ray output and penetration, it is necessary to maintain a close control of this factor in order to secure radiographs of uniform density. In many types of industrial radiography where it is desirable to maintain constant exposure conditions as regards focus-film distance, milliamperage, and exposure time, it is common practice to vary the kilovoltage in accordance with the thickness of the material to be examined so as to secure proper density in the radiographic image. Suppose, for example, it is desired to change from the radiog-

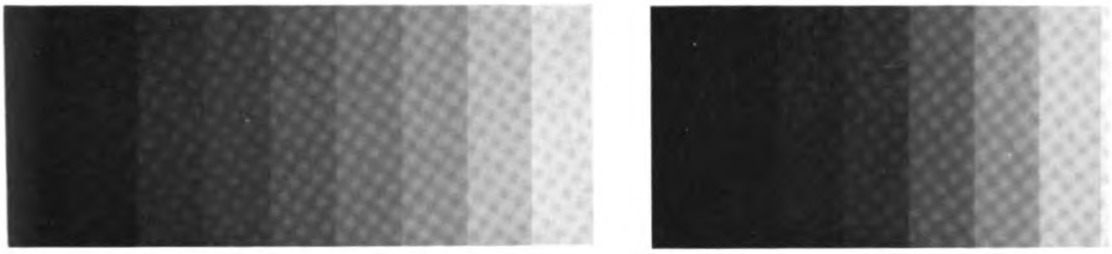

A—200 kv exposure B—100 kv exposure

Fig. 16—Radiographs of steel step tablet having a thickness range of 1/4 to 3/4-inch in 1/16-inch steps.

raphy of 1½-inch steel to 2-inch steel. The 2-inch steel will require more than ten times the exposure in milliampere-minutes at 170 kilovolts. However, increasing the kilovoltage to a little over 200 will yield a comparable radiograph with the same milliampere-minutes. Thus, kilovoltage is an important variable because economic considerations often require that exposure times be kept within fairly narrow limits. It is desirable, as a rule, to *use as low a kilovoltage as other factors will permit.*

CONTRAST

In a radiograph, the various intensities transmitted by the subject are rendered as different densities in the image. The density differences from one area to another constitute *radiographic contrast.* Any shadow or detail within the image is visible by reason of the contrast between it and its background or surrounding structures. Within appropriate limits, the greater the contrast or density differences in the radiograph, the more definitely various details stand out, and the finer the detail that can be seen. However, if over-all contrast is increased too much, there is an actual loss in visibility of detail in the higher and lower densities of the radiograph.

This principle is fully illustrated in Figure 16, which shows two radiographs of a steel tablet, one (A) exposed at a high tube voltage and the other (B) at a low voltage. It is apparent that in the middle tones the differentiation in the steps is greater in the low-voltage radiograph (B) than in the high-voltage radiograph (A). Near the ends, however, steps shown in (A) are entirely invisible in (B).

Radiographic contrast is a resultant both of *subject contrast* and *film contrast.* Subject contrast is governed by the range of radiation intensities transmitted by the specimen. A flat sheet of homogeneous material of nearly uniform thickness would have very low subject contrast, whereas a specimen transmitting a wide range of intensities would have a high subject contrast. Over-all subject contrast could be defined as the ratio of the highest to the lowest radiation intensities falling on the film. A given specimen could have a low contrast for gamma rays and a high contrast for soft x-rays. Contrast is also affected by scattered radiation, and its removal increases subject contrast.

Different films have different contrast characteristics. Thus, a contrasty film may give a radiograph of low contrast if the subject contrast is very low; and, conversely, a film of low contrast may give a contrasty radiograph of a specimen of sufficiently high subject contrast. With any given specimen, the contrast of the radiograph will depend on the kilovoltage, the contrast characteristics of the film, the density to which it is exposed, and processing conditions.

In the radiography of materials of approximately uniform thickness where the range of transmitted x-ray intensities is small, a technic producing high contrast will satisfactorily render all portions of the area of interest, and the radiographic sensitivity will be greater than with a technic producing low contrast. If, however, the part radiographed transmits a wide range of x-ray intensities, then a technic producing lower contrast will be necessary in order to record detail in all portions of the radiograph, probably at some sacrifice of radiographic sensitivity. (See Figure 16.)

High radiographic contrast may be obtained in the radiography of specimens transmitting too wide a range of intensities to be recorded by a single high contrast film, by loading the cassette with *two* high contrast films of *different speeds.* The kilovoltage and exposure are so chosen that the thick portions of the specimen are satisfactorily recorded on the faster film and the thin portions on the slower film. A variation of this method is to load the cassette or film holder with two sheets of the same kind of film.

With the proper exposure, details in the thick section of the specimen may be examined by viewing the two films superimposed with the images in register. The thin portions will be recorded on both films, either of which may be viewed alone.

Within the range of densities useful in practice, the contrasts of *Kodak Industrial X-ray Films, Types M* and *A*, and *No-Screen Film* increase continuously with increasing density. The contrast of *Type K Film* increases up to a density of about 2.0, after which it ceases to increase significantly. In the cases of *Type F Film* and *Blue Brand Film* contrast first increases to a maximum with increasing density and then decreases. Thus, the contrast of a radiograph depends to a large extent upon the density. This dependence is more fully discussed on page 36, and in the appendix, pages 83–90.

Film contrast increases with development time up to a limit determined by the properties of both the film and the developer. A development time of 5 minutes, at a temperature of 68° F., is recommended for most *Kodak Industrial X-ray Films* in *Kodak Liquid X-ray Developer and Replenisher* or *Kodak Rapid X-ray Developer.* Some films may be developed as long as 8 minutes at this same temperature to secure maximum speed and contrast. For specific recommendations, see page 57.

Radiographs of high contrast are apt to contain areas of high density in which detail cannot be seen with ordinary illumination. Methods of providing a high intensity of illumination for such areas are described in a later section, page 44.

REVERSAL

It is well known that the blackening or *density* of a film increases with increasing exposure up to a maximum value. This maximum density is usually so high that it is of little or no radiographic value. Increasing the exposure beyond this point results in an actual decrease of density. Thus, an exposure producing a high density through a thick part of a casting might yield a lower density under an adjacent thin part. Fortunately, several methods may be used to guard against this condition. Separate exposures may be made for the various thickness ranges, the thin regions may be built up with metal shot, or a filter placed over the window of the x-ray tube may lower sufficiently the range of x-ray intensities incident upon the film to avoid any difficulty from photographic reversal. Reversal does not occur commonly, because of the great latitude of x-ray film in the useful density region, but it may present a puzzling problem unless it is recognized as a natural photographic effect.

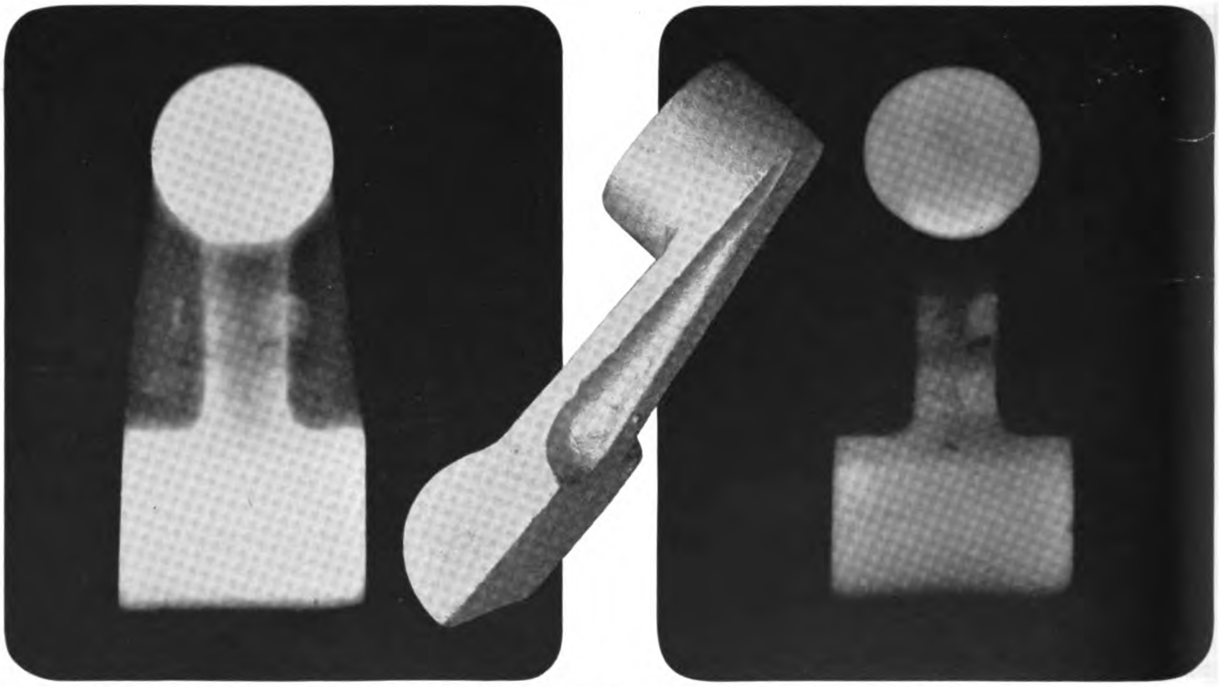


Fig. 17—Radiographs of multi-thickness cast steel part showing thin section detail on *Kodak Industrial X-ray Film, Type A* (left), and thick section detail on *Eastman No-Screen X-ray Film* (right). Both films were exposed simultaneously in the same cassette.

RADIOGRAPHIC SCREENS

When an x-ray beam strikes a film, usually less than 1 per cent of the x-ray energy is absorbed. Since the formation of the radiographic image is primarily governed by the absorbed radiation, more than 99 per cent of the available energy in the beam performs no useful photographic work. Obviously, any means of more fully utilizing this wasted energy, without complicating the technical procedure, is highly desirable. Two types of radiographic screens are used to achieve this end.

LEAD FOIL SCREENS

It has been found that for certain classes of industrial radiography, lead foil clamped on both sides of the film has a desirable effect upon the quality of the radiograph. The front foil need be only 0.004 to 0.006 inch thick so that its absorption of the primary x-ray beam is not serious. The back screen should be thicker to reduce back-scattered radiation. Such screens are available commercially.

Lead foil in direct contact with the film has three principal effects: (1) It increases the photographic action on the film, largely by reason of the electrons emitted and partly by the secondary x-rays generated in the lead; (2) it absorbs the longer wave length scattered radiation more than the primary; and (3) it intensifies the primary more than the scattered radiation. Effects (2) and (3) result in diminishing the effect of scattered radiation, thereby producing greater contrast and clarity in the radiographic image. This reduction in the scattered radiation decreases the total intensity of the radiation reaching the film and thereby lessens the net intensifying factor of the screens. The absorption of primary radiation by the front lead screen also diminishes the net intensifying effect, and if the incident radiation does not have sufficient penetrating power, the actual exposure required may be even greater than without screens. At best, the exposure time is one-half to one-third that without screens. The advantage of the screens in reducing scattered radiation, however, still holds.

Because of the improved radiographic quality they afford, lead screens are generally preferred to calcium tungstate screens in radiography with gamma rays and million-volt x-rays.

The quality of the radiation necessary to obtain intensification from lead screens depends upon the type of film, the kilovoltage, and the thickness and material through which the rays pass. In the radiography of aluminum, for example, the thickness must be about 6 inches, and the voltage as high as 160 kilovolts, to secure any advantage in exposure time with lead screens. In the radiography of steel, lead screens begin to give appreciable intensification with thicknesses in the neighborhood of ¼ inch, at voltages of 130 to 150 kilovolts. In the radiography of 1¼ inches of steel at 200 kilovolts, lead screens permit an exposure of about one-third that without the screens (intensification factor of 3). With gamma rays, the intensification factor of lead screens is about 2. Lead foil screens, however, do not detrimentally affect the definition or graininess of the radiographic image to any material degree, so long as the lead and film are in intimate contact.

Lead foil screens also diminish the effect of scattered radiation, particularly that which undercuts the object, when primary rays strike the portions of the film holder or cassette outside the area covered by the object. Scattered radiation from the specimen itself is cut almost in half by lead foil screens, contributing to maximum clarity of detail in the radiograph; this advantage is obtained even under conditions where the lead screens make necessary an increase in exposure. A more exhaustive discussion of scatter will be found in the chapter on "Scattered Radiation," starting with page 25.

In radiography with gamma rays or high-voltage x-rays, films loaded in metal cassettes without screens are apt to record the effects of secondary electrons generated in the lead-covered back of the cassette. These electrons, passing through the felt pad on the cassette cover, produce a mottled appearance due to the structure of the felt. Films loaded in the customary lead-backed cardboard exposure holder may also show a pattern of the structure of the paper which lies between the lead and the film (Figure 93, page 109). To avoid these effects, the film should be enclosed between double lead screens, care being taken to insure good contact between film and screens. Thus, lead screens are essential in practically all radiography with gamma rays or million-volt x-rays. If, for any reason, screens cannot be used with these radiations, the film should be loaded in a lightproof paper or cardboard holder, *without any metal backing*. Contact between the film and lead foil screens is essential to good radiographic quality. Areas in which contact is lacking produce "fuzzy" images as shown in Figure 18.

Lead foil for screens must be selected with extreme care. Commercially pure lead is satisfactory. An alloy of 6% antimony and 94% lead, being harder and stiffer, has better resistance to wear and abrasion. Tin-coated lead foil should be avoided since irregularities in the tin cause a variation in the intensifying factor of the screen, resulting in mottled radiographs. Minor blemishes do not affect the usefulness of the screen, but large "blisters" or cavities should be avoided.

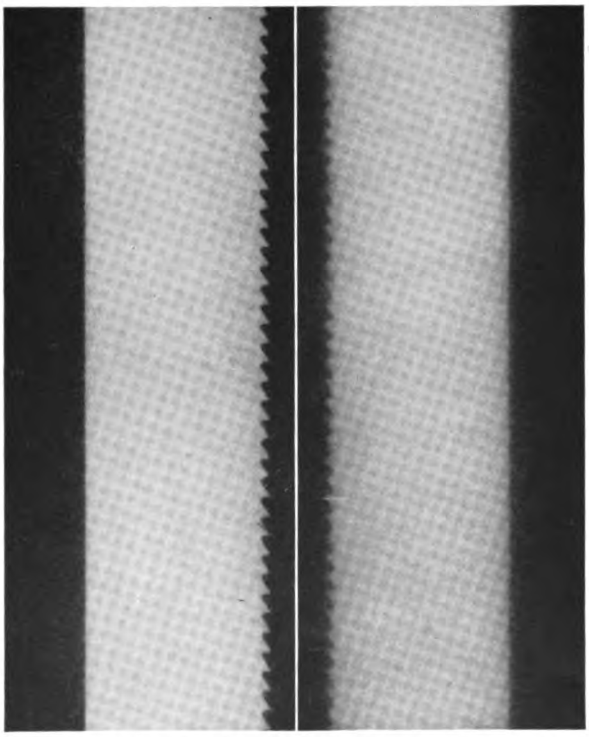


Fig. 18—Good contact between film and lead foil screens gives sharp image (left). Poor contact results in fuzzy image (right).

Most of the intensifying action of a lead foil screen is caused by the electrons emitted under x-ray or gamma-ray excitation and, because of the high electron absorption in light materials, the surface must be kept free from dirt and lint. Grease and lint may be removed from the surface of lead foil screens with a solvent such as carbon tetrachloride. If more thorough cleaning is necessary screens may be very gently rubbed with the finest grade of steel wool. Films may be fogged if left between lead screens longer than is reasonably necessary, particularly under conditions of high temperature and humidity. When screens have been freshly cleaned with an abrasive, this effect will be increased and prolonged contact between film and screens should be delayed at least twenty-four hours.

Indications for Use of Lead Foil Screens

Lead foil screens have a wide range of usefulness. They permit a reduction in exposure time with thicknesses of metal above about ¼-inch of steel and kilovoltages above about 130. Their use is recommended in all cases where they exhibit this intensifying action. However, they may be employed even in some cases where they do not permit a reduction, but even necessitate an increase in exposure time. The chief criterion should be the quality of the radiograph. Lead screens should be used whenever they improve radiographic quality.

FLUORESCENT SCREENS

Certain chemicals *fluoresce*, that is, have the ability to absorb x-rays and immediately emit light. The intensity of the light emitted depends upon the intensity of the incident x-radiation. The compound that is most commonly employed in intensifying screens is the white crystalline salt, calcium tungstate, because of its effectiveness as a fluorescent agent and its general advantages in manufacture and use. It is finely powdered, mixed with a suitable binder, and coated in a thin, smooth layer on a special cardboard support to form the screen.

For the exposure, the film is clamped firmly be-

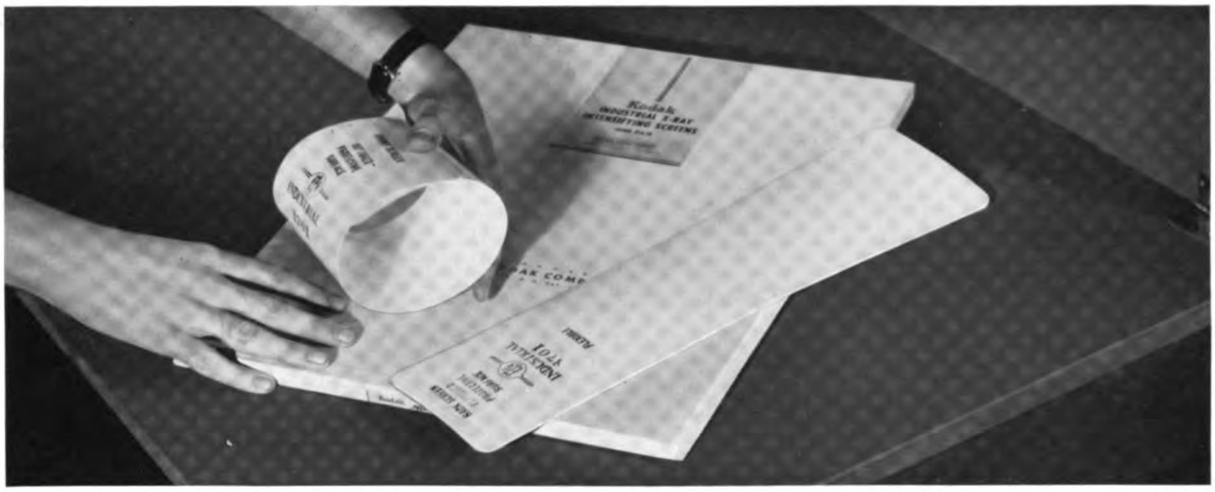


Fig. 19—The flexibility of *Kodak Industrial X-ray Intensifying Screens* permits bending the screens to fit the circumference of small objects.

tween a pair of these screens. The photographic effect on the film, then, is the sum of the effects of the x-rays and of the light emitted by the screens. A few examples will serve to illustrate the importance of intensifying screens in the reduction of exposure time. In medical radiography, the exposure is from 1/15 to 1/30 as much with screens as without. That is, the *intensification factor* varies from 15 to 30, depending on the kilovoltage and the type of screen used. In the radiography of ½-inch steel at 150 kilovolts, a factor as high as 125 has been observed. At this condition, the intensification factor has about reached its maximum, and it diminishes both for lower voltage and thinner steel and for higher voltage and thicker steel. Using gamma rays for very thick steel, the factor may be 10 or less.

Intensifying screens are needed in the radiography of steel thicknesses greater than 1½ inches at 200 KvP, and greater than 3 inches at 400 KvP. With gamma rays and million-volt x-rays, calcium tungstate intensifying screens are not employed, as a rule, since they tend to give excessive graininess to the image. In the radiography of light metals, intensifying screens are rarely necessary, but should they be required, the best choice would be *Kodak X-ray Intensifying Screens* (*High-Definition*), which are designed particularly for sharpness of definition and the reproduction of fine detail at relatively low kilovoltages.

Since in the radiography of steel with intensifying screens high photographic speed is generally necessary, *Kodak Industrial X-ray Intensifying Screens* are to be preferred. These are much faster than the *High Definition Screens*, and render practically as good detail as the latter in the radiography of steel thicknesses greater than ½ inch. *Kodak Industrial X-ray Intensifying Screens* are sufficiently flexible to be bent to a 4-inch radius when necessary to accommodate them to the shape of the object under examination.

The following characteristics are essential to economical routine use of screens: a minimum of afterglow which would superimpose the effects of previous exposures; surfaces that will not abrade or scratch readily; ease in mounting; and long life. *Kodak Industrial X-ray Intensifying Screens* are designed to fulfill these requirements.

Use and Mounting of Screens

Intensifying screens are mounted in pairs in rigid holders, called cassettes, so that the fluorescent surface of each is in direct contact with one of the emulsion surfaces of the film. Intimate contact of the screens and the film over their entire areas is essential, because poor contact allows the fluorescent light to spread and produce a blurred image as shown in Figure 21, page 22.

Intensifying screens are normally mounted in cassettes by the x-ray dealers who are usually equipped to provide this service. Suitable methods are necessary to avoid physical unevenness that would result from any thick bonding material. The adhesive must not result in discoloration of the screen, as even a small degree of discoloration will reduce their effective speed. In addition, the adhesive must not cause fogging of the film.

Tape having a very thin base and adhesive coating

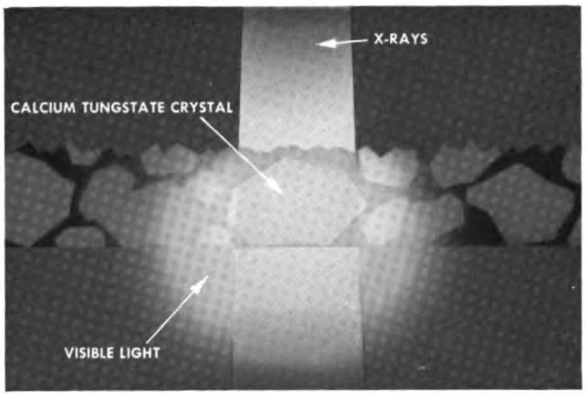


Fig. 20—Visible light from a fluorescent screen spreads beyond the x-ray beam exciting the fluorescence.

on both sides offers a convenient mounting method, but must neither discolor the screen nor cause fogging of the film. Such a tape could be applied at the edges of the backing of the back screen and at the corners of the backing of the front screen. Any material used should have low x-ray absorption so that no x-ray image results.

Care of Screens

Fluorescent light from intensifying screens obeys all the laws of visible light and cannot pass through opaque bodies, as do x-rays. In order to avoid extraneous shadows caused by absorption of the fluorescent light by foreign matter during exposure, dust and dirt particles must not be allowed to collect between film and screen surfaces, and stains upon the screens must be avoided. Cleanliness of the order desirable for handling film and screens is sometimes difficult to maintain, but much can be done by stressing its need and eliminating carelessness.

It is important that fluorescent intensifying screens *never be subjected to the full intensity of an x-ray beam* when making a radiograph. If the specimen more than covers the screen area, or if proper masking is provided, there is practically no danger of discoloring the screen, or of producing afterglow, from excessive exposure.

As a matter of routine, all cassettes should be tested periodically to check up on the contact between the screens and the film. This may be easily done by securing a piece of wire screening (any size mesh, from 1⁄16-inch to ½-inch, is satisfactory) and mounting it so that it lies fairly flat. The cassette is then loaded with a film, the wire screening placed on the exposure side of the cassette, and a flash exposure made. If there are poor contact areas, the result will be as shown in Figure 21, page 22. If there is proper contact, the shadow of the wire mesh will be outlined sharply, as in Figure 22.

The remedy for faulty contact is simple. All that is necessary is to bring the areas which have caused "fuzzy" images closer to the film. A good way is to build them up with thin paper. The interleaving paper folders in which *Kodak Industrial X-ray Films* are packed are very satisfactory for this purpose. Merely putting sheets of blotting paper or felt over the entire surface is seldom satisfactory, for, unless the padding is very resilient, the condition will be aggravated.

If there is a lack of contact in the center, a series of oval sheets of paper, each slightly smaller in area, should be cut out. This "pack" can be held together by minute dabs of glue or paste and placed under the back screen, next to the felt pad, which is then mounted in the usual manner. Any other area

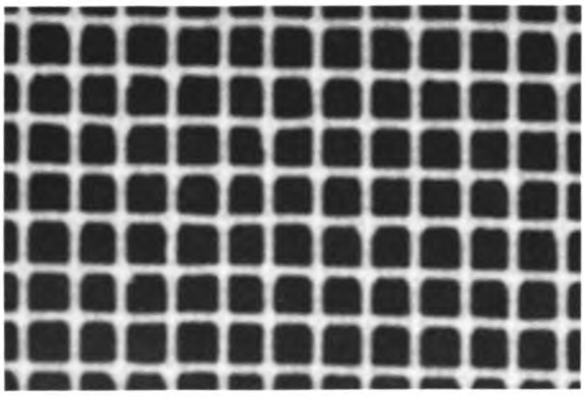


Fig. 21—Poor contact between intensifying screens and film; fuzzy image.

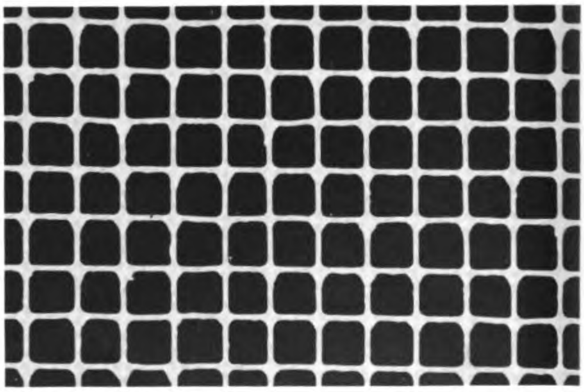


Fig. 22—Good contact between intensifying screens and film; sharp image.

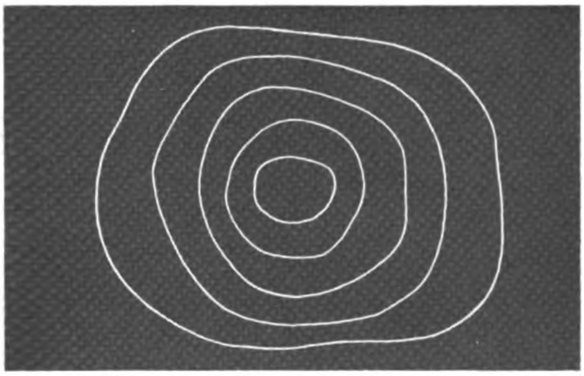


Fig. 23—Paper "pack" to remedy poor film-screen contact near the center of a cassette.

may be built up in the same way.

Calcium tungstate screens may be stored in the processing room but away from chemicals and other sources of contamination. The sensitive surfaces should not be touched, because finger marks and dust particles may show in the radiograph and interfere with accurate interpretation. The surfaces of *Kodak Industrial X-ray Screens* are given maximum safeguard against abrasions and wear by a special protective coating. Waterproof and applied to both sides, this coating also precludes warping of the screens by preventing absorption of moisture. Thus, if the surfaces accidentally acquire markings, they may be cleaned by washing with a mild hand soap and water, and then drying thoroughly with a soft cloth. Hydrogen peroxide or other common cleaning agents should never be used for this purpose because their chemical composition will cause fogging of the sensitive film emulsions.

The use of thin cellulose sheets for protecting the active surface of intensifying screens is particularly objectionable because, under certain atmospheric conditions, merely opening the cassette is liable to produce static electrical discharges between the sheets and the film. The result will be circular or treelike black markings in the radiograph.

Indications for Use of Fluorescent Screens

The advantage in using calcium tungstate intensifying screens lies in the great reductions in exposure time that their use permits. As a corollary to this, the radiography of relatively thick specimens on x-ray machines of moderate power is facilitated. For instance, using calcium tungstate screens, 3 inches of steel may be radiographed at 250 kilovolts with a reasonable exposure time.

Fluorescent screens give poorer definition in the radiograph, compared to a radiograph made directly or with lead foil screens. For this reason they are seldom used except when economy demands the shorter exposure times their use allows. The poorer definition results from the spreading of the visible light emitted from the screens as shown in Figure 20. The light from any individual crystal spreads out beyond the confines of the original x-ray beam which excites the crystal to fluorescence. The overlapping of many such minute areas accounts for the blurring of outlines in the radiograph.

If a general rule can be given, it is that calcium tungstate screens should be used only when the exposure necessary without them would be prohibitive.

CASSETTES AND FILM HOLDERS

When intensifying or lead foil screens are used, good, uniform contact between screens and film is of prime importance. The use of rigid, spring-back cassettes is the most certain way of obtaining such intimate contact. If tests for screen contact are made at reasonable intervals, no further attention need be given the matter.

Cardboard or thin plastic exposure holders are cheaper, easier to handle in large numbers, and are flexible as compared with rigid cassettes. However, if screens are to be used in them, special precautions must be taken to insure good contact. The exact means used will depend upon the object radiographed. Exposure holders may be pressed or clamped against the specimen, or the weight of the specimen or the flexing of the holder as it is bent to fit inside some structure may be used to insure contact.

Two points should be noted, however. First, these methods do not guarantee *uniform* contact, and hence the definition of the image may vary from area to area of the film. This variation of definition may not be obvious and may cause errors in the interpretation of the radiograph. Second, such holders do not always adequately protect the film from mechanical damage. A projection on the film side of the specimen may cause a relatively great pressure on a small area of the film. This may produce, in the finished radiograph, a light or dark pressure mark which may be mistaken for a flaw in the specimen.

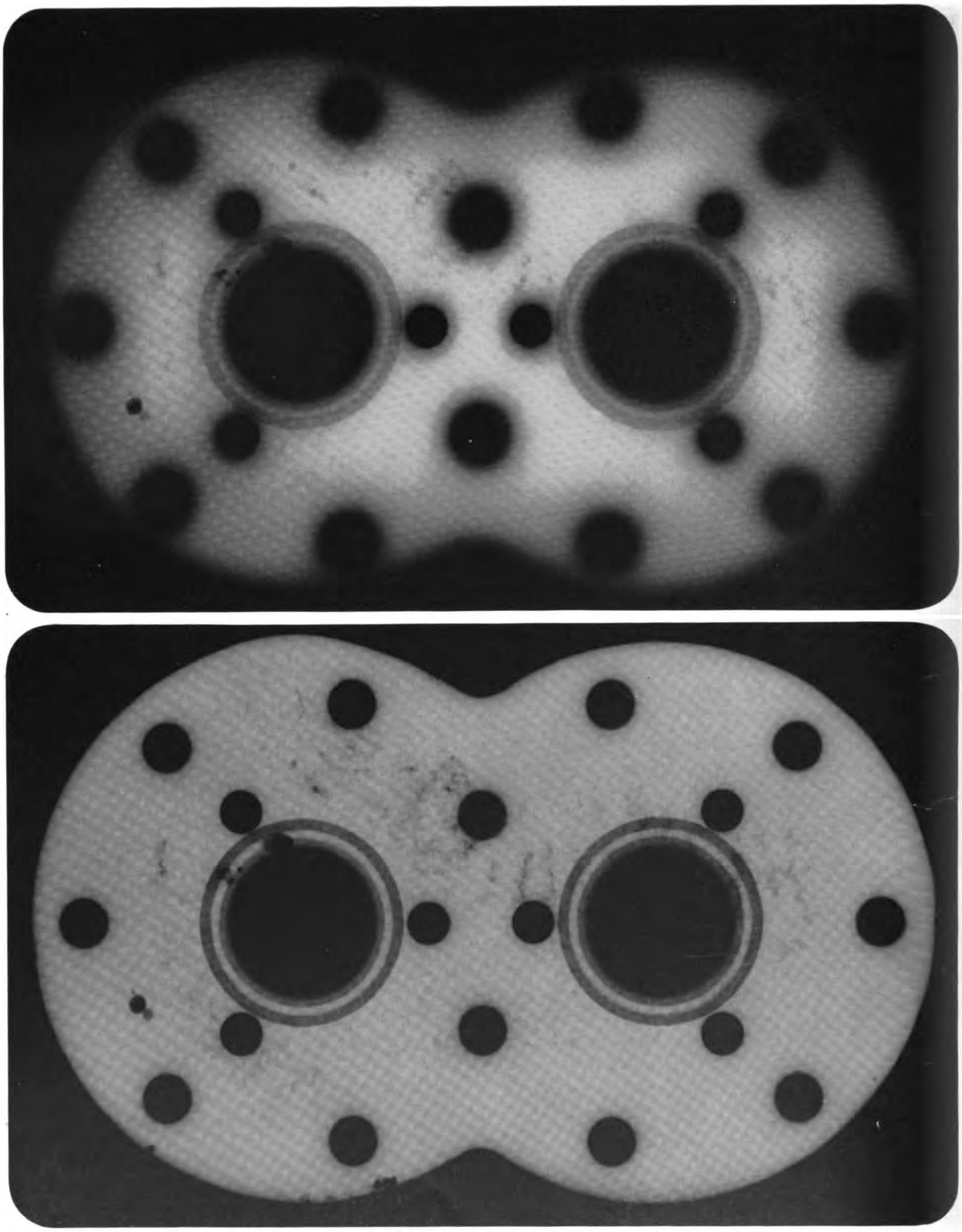


Fig. 24—Lead foil screens remove scatter and increase radiographic contrast. Specimen is 1/4-inch steel radiographed at 120 kilovolts. Above, no screens; below, lead foil screens. Although in this case lead foil screens necessitate some increase in exposure, they greatly improve radiographic quality.

SCATTERED RADIATION

When a beam of x-rays strikes any object, some of the rays are absorbed, some are scattered and some pass straight through. Electrons of the atoms comprising the object scatter radiation in all directions, much as light is dispersed in a fog. The wave lengths of much of the radiation are increased by the scattering process, and hence the scatter is always somewhat "softer" or less penetrating than the unscattered primary radiation. Any material, whether specimen, cassette, table top, walls or floor, receiving the direct radiation from the tube, is a source of scattered radiation. Unless suitable measures are taken to reduce the effects of scatter, it will cause a haziness or fog over the whole image or parts of it, thus reducing contrast.

In the radiography of thick materials, scattered rays form the greater percentage of the total radiation incident upon the film. For example, in the radiography of a ¾-inch thickness of steel, the scattered radiation from the specimen is almost twice as intense as the primary radiation reaching the film. In the radiography of a 2-inch thickness of aluminum, the scattered radiation is 2½ times as great as the primary radiation. As may be expected, preventing this scattered radiation from reaching the film produces marked improvement in the quality of the radiographic image.

As a rule, the greater portion of the scattered radiation affecting the film arises in the specimen under examination (A in Figure 25). However, any portion of the film holder or cassette which extends beyond the boundaries of the specimen, and thereby receives direct radiation from the x-ray tube, also becomes the source of scattered radiation which can affect the film. The influence of this scatter is most noticeable just inside the borders of the image (B in Figure 25). In a similar manner, primary radiation striking the film holder or cassette through a thin portion of the specimen will cause scattering into the shadows of the adjacent thicker portions. Such scatter is called *undercut*. Another source of scatter which may undercut a specimen is shown as C in Figure 25. If a filter is used near the tube, this too will scatter x-rays. However, scattering from this source is of negligible importance. In addition, any other material, such as a wall or floor, on the film side of the specimen may scatter an appreciable quantity of x-rays back to the film, especially if this

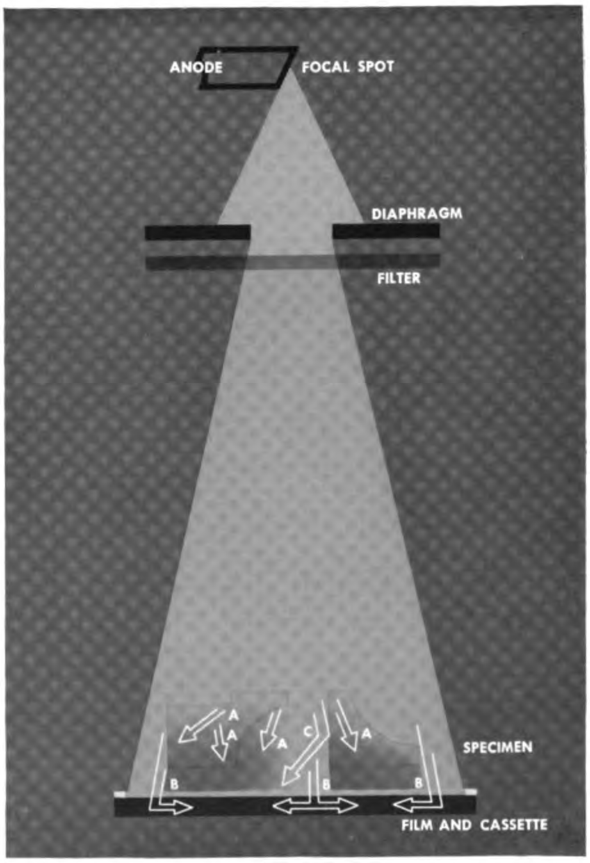


Fig. 25—Sources of scattered radiation. (A) Transmitted scatter. (B) Scatter from cassette. (C) "Reflection" scatter.

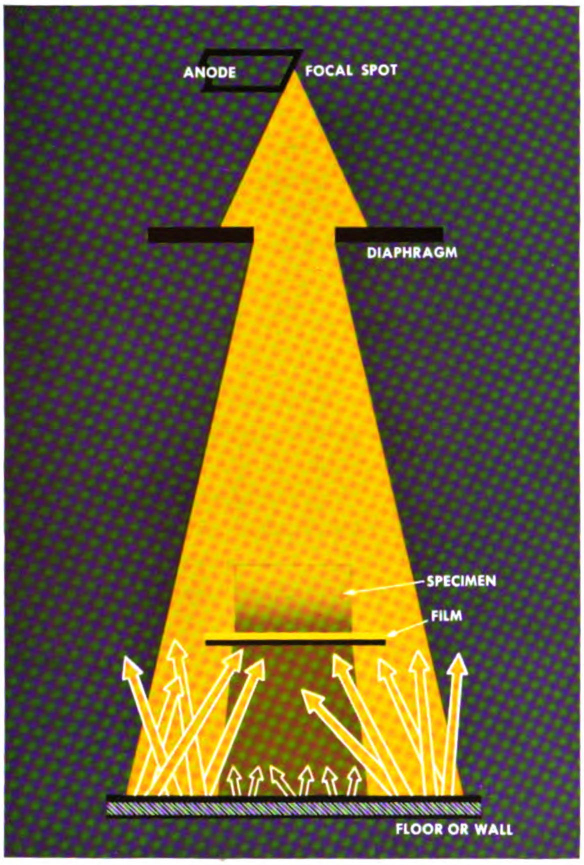


Fig. 26—Intense back-scattered radiation may originate in floor or wall. Coning, masking, or diaphragming should be employed. Backing the cassette with lead may give adequate protection.

material receives direct radiation from the x-ray tube (Figure 26). This is referred to as back-scattered radiation.

REDUCTION OF SCATTER

Although scattered radiation can never be completely eliminated, a number of means are available for the reduction of its effect.

Masks and Diaphragms

Scattered radiation originating in matter outside the specimen is most serious for specimens which have high absorption for x-rays, as the scattering from external sources may be large compared to the primary image-forming radiation which reaches the film through the specimen. Often, the most satisfactory method of lessening this scatter is by the use of cut-out diaphragms or some other form of mask mounted over or around the object radiographed. If many specimens of the same article are to be radiographed, it may be worth while to cut an opening of the same shape, but slightly smaller, in a sheet of lead and place this on the object. The lead serves to reduce the exposure in surrounding areas to a negligible value and therefore to eliminate scattered radiation from this source. Since scatter also arises from the specimen itself, it is good practice, wherever possible, to limit the cross section of an x-ray beam to cover only the area of the specimen which is of interest in the examination.

For occasional pieces of work where a cut-out diaphragm would not be economical, packing barium clay around the specimen will serve the same purpose. It should be thick enough so that the film density under the clay is considerably less than that under the specimen. Otherwise, the clay itself will contribute appreciable scattered radiation.

It may be found advantageous to place the objects in aluminum or thin sheet-iron pans and to

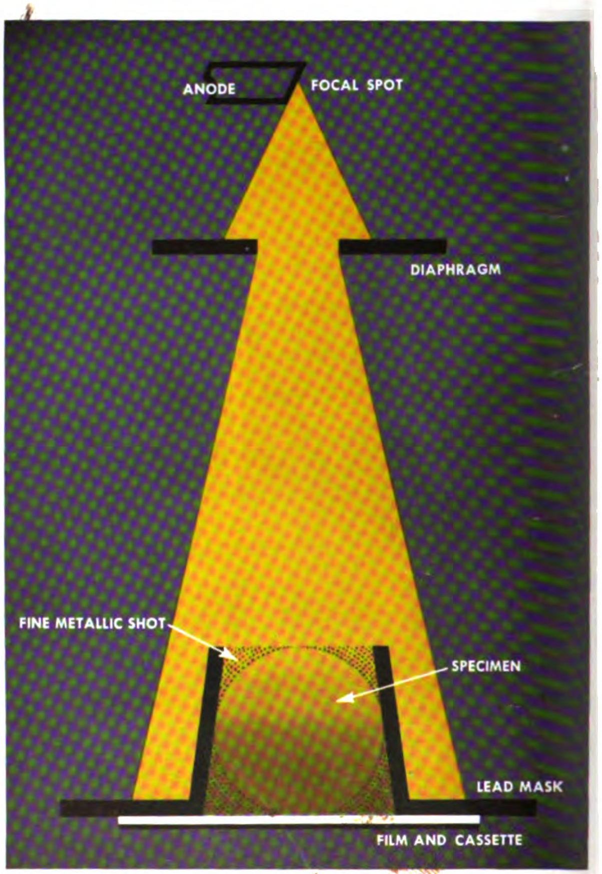


Fig. 27—The combined use of metallic shot and a lead mask is conducive to good radiographic quality. If several round bars are to be radiographed, they may be separated with lead strips held on edge in a wooden frame and the voids filled with fine shot.

use a liquid absorber. A combined saturated solution of lead acetate and lead nitrate is satisfactory. This is prepared by dissolving approximately 3½ pounds of lead acetate in 1 gallon of hot water. When the lead acetate is in solution, about 3 pounds of lead nitrate may be added. (CAUTION! This solution is poisonous.) This solution is a strong absorber of x-rays because of its high lead content. Carbon tetrachloride has been used as a masking agent for aluminum, but personnel should guard against excessive exposure to its fumes. In masking with liquids, care must be used to eliminate bubbles which may cling to the surface of the specimen.

One of the most satisfactory arrangements, combining effectiveness and convenience, is to surround the object with copper or steel shot having a diameter of about 0.01 inch (Figure 27). This material "flows" without running badly. It is also very effective for filling cavities in irregular objects, such as castings, where a normal exposure for thick parts would result in overexposure for thinner parts. Of course, it is preferable to make separate exposures for thick and thin parts, but this is not always practicable.

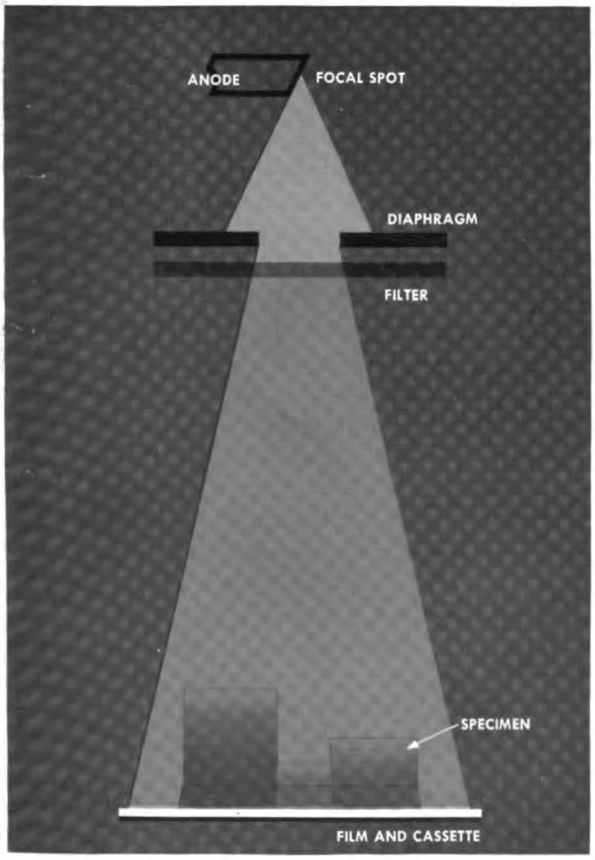


Fig. 28—A filter placed near the x-ray tube reduces subject contrast and eliminates much of the secondary radiation which tends to obscure detail in the periphery of the specimen.

In some cases, a lead diaphragm or lead cone on the tube head may be a convenient way to limit the area covered by the x-ray beam. Such lead diaphragms are particularly useful where the desired cross section of the beam is a simple geometrical figure, such as a circle, square, or rectangle.

Filters

A simple metallic filter mounted in the x-ray beam near the x-ray tube (Figure 28) may adequately serve the double purpose of masking the surroundings and of eliminating overexposure in the thin regions of the specimen. Such a filter is particularly useful in the reduction of scatter undercut in cases where a mask around the specimen is impractical or where the specimen would be injured by chemicals or shot. Of course, an increase in exposure or kilovoltage will be required to compensate for the additional absorption, but in cases where the filter method is applicable, this is not serious unless the limit of the x-ray machine has been reached.

The underlying principle of the method is that the addition of the filter material causes a much greater change in the amount of radiation passing through thin parts than through thicker parts. Suppose that the shape of a certain steel specimen is as shown in Figure 28, and that the thicknesses are ¼ inch, ½ inch, and 1 inch. This specimen is radiographed first with no filter, and again with a filter of ¼-inch steel placed near the tube.

Column 3 of the tabulation below shows the percentage of the original x-ray intensity remaining after the addition of the filter, assuming both exposures were made at 180 KvP. (These values were derived from actual exposure chart data.)

Region	**Specimen Thickness**	**Percentage of original x-ray intensity remaining after addition of filter**
Outside specimen	0″	under 5%
Thin section	¼″	about 30%
Medium section	½″	about 40%
Thick section	1″	about 55%

Note that the greatest *percentage change* in x-ray intensity is under the thinner parts of the specimen and in the film area immediately surrounding it. The filter reduces by a large ratio the x-ray intensity passing through the thin sections or striking the cassette around the specimen, and hence reduces the undercut of scatter from these sources. Thus, *in regions of strong undercut*, contrast is *increased* by the use of a filter, since the only effect of the undercutting scattered radiation was to obscure the desired image.

In regions where the undercut is negligible, a filter has the effect of *decreasing* the contrast in the finished radiograph. Although frequently the highest possible contrast is desired, there are certain instances in which too much contrast is a definite disadvantage. For example, it may be desired to render detail visible in all parts of a specimen having wide variations of thickness. If the exposure is made to give a usable density under the thin part, the thick region may be underexposed. If the exposure is adjusted to give a suitable density under the thick parts, the image of the thin sections may be grossly overexposed.

A filter reduces excessive subject contrast (and hence radiographic contrast) by hardening the radiation. The longer wave lengths do not penetrate the filter to as great an extent as do the shorter wave lengths. Therefore, the beam emerging from the filter contains a higher proportion of the more penetrating wave lengths. Figure 29 illustrates this graphically. In the sense that a more penetrating beam is produced, filtering is analogous to increasing the kilovoltage. However, it requires a comparatively large change in kilovoltage to change the hardness of an x-ray beam to the same extent as will be produced by the addition of a small amount of filtration.

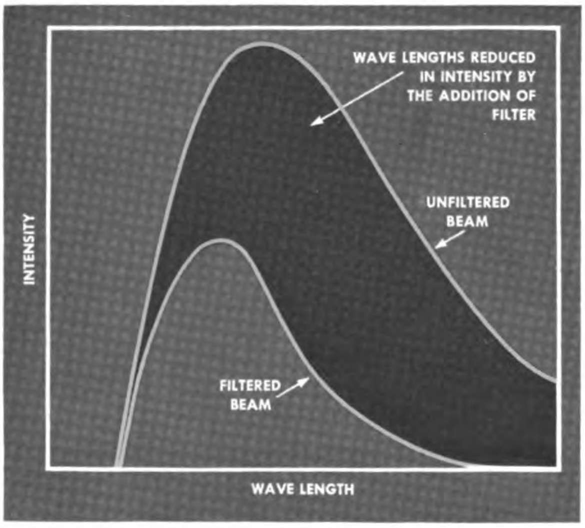


Fig. 29—Curves illustrating the effect of a filter on the composition and intensity of an x-ray beam.

Although filtering reduces the total quantity of radiation, most of the wave lengths removed are those which would not penetrate the thicker portions of the specimen in any case. The radiation removed would only result in a high intensity in the regions around the specimen and under its thinner sections, with the attendant scattering undercut and overexposure. The harder radiation obtained by filtering the x-ray beam produces a radiograph of lower contrast, thus permitting a wider range of specimen thicknesses to be recorded on a single film than would otherwise be possible.

Thus, a filter can act either to increase or decrease the net contrast. The contrast and penetrameter visibility are *increased* by the removal of scatter which undercuts the specimen, and *decreased* by the hardening of the original beam. The nature of the individual specimen will determine which of these effects will predominate or whether both will occur in different parts of the same specimen.

The choice of filter material should be made on the basis of availability and ease of handling. For the same filtering effect, the thickness of filter required is less for those materials having higher absorption. In many cases, copper or brass is the most useful, since filters of these materials will be thin enough to handle easily, yet not so thin as to be delicate.

Definite rules as to filter thicknesses are difficult to formulate exactly, since the amount of filtration required depends not only upon the material and thickness range of the specimen, but also upon the distribution of material in the specimen and upon the amount of scatter undercut that it is desired to eliminate. In the radiography of aluminum, a filter of copper 0.04 of the greatest thickness of the specimen should prove the largest necessary. With steel, a copper filter should ordinarily be 0.2, and a lead filter 0.03, of the greatest specimen thickness for the greatest useful filtration. The foregoing values are maximum values, and, depending on circumstances, useful radiographs may often be made with far less filtration.

In radiography with x-rays up to at least 250 KvP, it has been found preferable to place the filter near the x-ray tube; if inserted between the object and the film, the filter itself contributes scattered radiation to the film. Although the filter near the tube gives rise to scattered radiation, this radiation is emitted in all directions, and since the film is far from the filter, scattered radiation from it reaching the film is very faint.

Further advantages of placing the filter near the x-ray tube are that the specimen-film distance is kept to a minimum and that scratches and dents in the filter are so blurred that their images do not appear on the film.

Lead Foil Screens

Double lead foil screens, mounted in contact with the film, diminish the effect on the film of scattered radiation from all sources. The effect of lead screens in lessening scatter occurs regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure. The nature of the action of lead screens is discussed more fully in the section on "Lead Foil Screens," page 19.

The *Eastman X-ray Exposure Holder* incorporates a sheet of lead foil in the back for the specific purpose of protecting the film from backscatter. This lead will not serve as an intensifying screen because of its paper facing. If intensifying screens are used with these holders, *definite means must be provided to insure good contact.*

X-ray film cassettes also are usually fitted with a sheet of lead foil in the back for protection against backscatter.

In using such a cassette or film holder with gamma rays or with million-volt x-rays, the film should always be enclosed between double lead screens; otherwise, the secondary radiation from the lead backing is sufficient to penetrate the intervening felt or paper and cast a shadow of the structure of this material on the film, giving a granular or mottled appearance. This effect can also occur at voltages as low as 200 kilovolts unless the film is enclosed between lead foil or calcium tungstate screens.

Grid Diaphragms

One of the most effective ways to reduce scattered radiation from an object being radiographed is through the use of a Potter-Bucky diaphragm. This apparatus (Figure 30) consists essentially of a moving grid which, during the exposure, passes between the object and the film. The grid is composed of a series of strips of lead held in position by intervening strips of wood. The lead strips are tilted so that the plane of each is in line with the focal spot of the tube. The wood-filled slots between the lead strips usually are about six times as deep as they are wide. The parallel lead strips have the function of absorbing the very divergent scattered rays from the object being radiographed, so that most of the exposure is made by the primary rays emanating from the focal spot of the tube.

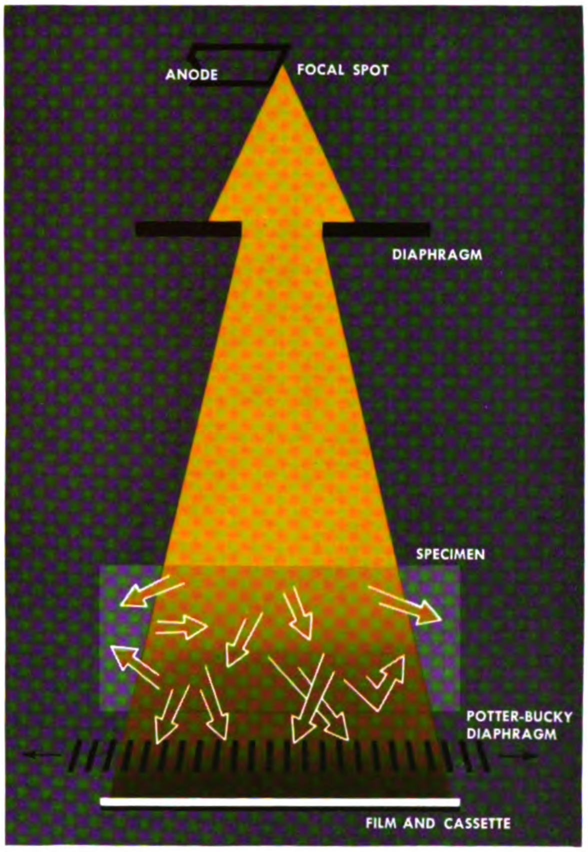


Fig. 30—Schematic diagram showing how the primary x-rays pass between the lead strips of the Potter-Bucky diaphragm while most of the secondary x-rays are absorbed because they strike the sides of the strips.

The use of the Potter-Bucky diaphragm in industrial radiography complicates the technic to some extent, and necessarily limits the flexibility of arrangement of the x-ray tube, the specimen, and the film. For these reasons, it is seldom used in the industrial field.

Special forms of the Potter-Bucky diaphragm have been designed for the radiography of steel with voltages from 200 to 400 kilovolts. The form of Potter-Bucky diaphragm used in medical radiography, if provided with sufficiently slow grid travel, would doubtless be suitable for the radiography of large castings of aluminum or magnesium.

SCATTERING IN MILLION-VOLT RADIOGRAPHY

The problem of scattered radiation in million-volt radiography is somewhat different from that at lower voltages. There is much less need for heavy filtration at the tube, and some evidence exists to show that, in some cases, a filter between film and specimen is helpful in reducing the effect of scatter. Because of the extremely penetrating nature of the beam, a filter, where needed, must be relatively thick compared to those used at the lower voltages. For this reason, lead is the most suitable filter material, especially where the filter is to be used on the cassette. Reasonable care should be used in handling the lead because dents may be recorded in the radiograph.

A very important point is to block off all radiation, except the useful beam, with heavy (½-inch to 1-inch) lead at the anode. Unless this is done, radiation striking the walls of the x-ray room will scatter back in such quantity as to affect seriously the quality of the radiograph. This will be especially noticeable if the specimen is thick or has projecting parts relatively far from the film.

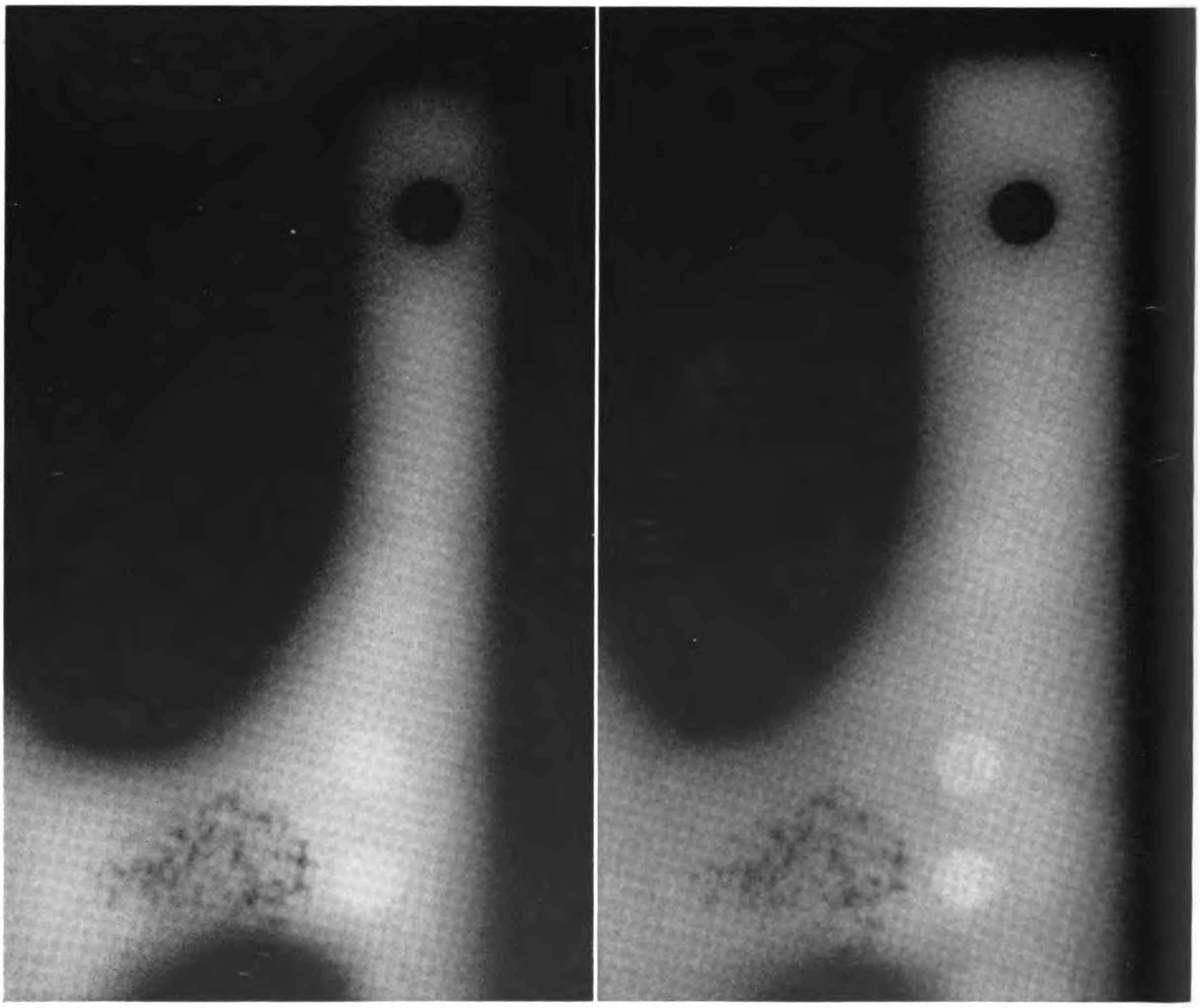


Fig. 31—Sections of radiographs of unmasked 1⅛-inch steel casting, made at 200 kilovolts without filtration (left), and as improved by filtration at the tube (right).

ARITHMETIC OF EXPOSURE

MILLIAMPERAGE—TIME—DISTANCE RELATIONSHIPS

The necessary calculations for any changes in focus-film distance (D), milliamperage (M), or time (T), are matters of simple arithmetic and are illustrated in the following examples. As noted earlier, kilovoltage changes cannot be calculated directly but must be obtained from the exposure chart of the equipment or the operator's logbook.

Milliamperage-Distance Relation

The milliamperage employed in any exposure technic should be in conformity with the manufacturer's rating of the x-ray tube. In most laboratories, however, a constant value of milliamperage is usually adopted for convenience.

Rule: The milliamperage (M) required for a given exposure is directly proportional to the square of the focus-film distance (D).

Example: Suppose that with a given exposure time and kilovoltage, a properly exposed radiograph is obtained with 5 milliamperes (M_1) at a distance of 12 inches (D_1), and that it is desired to increase the sharpness of detail in the image by increasing the focus-film distance to 24 inches (D_2). The correct milliamperage (M_2) to obtain the desired radiographic density at the increased distance (D_2) may be computed from the proportion:

$$M_1 : M_2 :: D_1^2 : D_2^2 \text{ or } \frac{M_1}{M_2} = \frac{D_1^2}{D_2^2}$$

$$5 : M_2 :: 12^2 : 24^2 \text{ or } \frac{5}{M_2} = \frac{12^2}{24^2}$$

$$M_2 = 5 \times \frac{24^2}{12^2}$$

$$M_2 = 20 \text{ milliamperes}$$

When very low kilovoltages, say 20 kilovolts or less, are used, the x-ray intensity will decrease with distance more rapidly than calculations based on the inverse square law would indicate. This is due to the absorption of the x-rays by the air. Most industrial radiography, however, is done with radiation so penetrating that the air absorption may be neglected. This comment applies also to the time-distance relationship below.

Milliamperage-Time Relation

Rule: The milliamperage (M) required for a given exposure is inversely proportional to the time (T). Another way of expressing this is to say that for a given set of conditions (voltage, distance, etc.), the product of milliamperage and time is constant for the same photographic effect. Thus, $M_1T_1 = M_2T_2 = M_3T_3 = C$, a constant. This is commonly referred to as the *reciprocity law.* (Important exceptions will be discussed on page 32.)

Example: Assuming that a good radiograph is obtained with 15 milliamperes (M_1) in ½ minute (T_1), what will be the correct time if it is necessary to change the milliamperage to 5?

$$M_1 : M_2 :: T_2 : T_1 \text{ or } \frac{M_1}{M_2} = \frac{T_2}{T_1}$$

or as shown above:

$$M_1T_1 = M_2T_2$$

$$15 : 5 :: T_2 : 0.5 \text{ or } \frac{15}{5} = \frac{T_2}{0.5}$$

$$T_2 = 0.5 \times \frac{15}{5}$$

$$T_2 = 1.5 \text{ minutes}$$

Time-Distance Relation

Rule: The exposure time (T) required for a given exposure is directly proportional to the square of the focus-film distance (D).

Example: When a focus-film distance of 30 inches (D_1), is changed to 24 inches (D_2), an exposure time of 10 minutes (T_1) must be changed to T_2 minutes:

$$T_1 : T_2 :: D_1^2 : D_2^2 \text{ or } \frac{T_1}{T_2} = \frac{D_1^2}{D_2^2}$$

$$10 : T_2 :: 30^2 : 24^2 \text{ or } \frac{10}{T_2} = \frac{30^2}{24^2}$$

$$T_2 = 10 \times \frac{24^2}{30^2}$$

$$T_2 = 6.4 \text{ minutes}$$

THE RECIPROCITY LAW

In the sections immediately preceding, it has been assumed that exact compensation for a decrease in the time of exposure may be made by increasing the milliamperage according to the relation $M_1T_1 = M_2T_2$. This may be written $MT = C$ and is a case of the general photographic law that the same photographic effect is produced for $IT =$ constant, where I is intensity of the light and T is the time of exposure. It is called the *reciprocity law* and is *accurately true for direct x-ray and lead screen exposures.* For exposures to light, it is not quite accurate and, since some radiographic exposures are made with light by the use of fluorescent intensifying screens, the law cannot be strictly applied. Errors due to assuming the validity of the reciprocity law usually are so small that they are not noticeable in the type of examples given in the preceding sections. Departures may be apparent, however, if the intensity is changed by a factor of four or more. Since intensity may be changed by changing the focus-film distance, failure of the reciprocity law will make it appear as a violation of the inverse square law. Applications of the law in a wide intensity range sometimes arise and the relation between results and calculations may be misleading unless the possibility of failure of the reciprocity law is kept in mind. Failure of the reciprocity law means that the *efficiency* of light-sensitive emulsions in utilizing the light energy depends upon the light *intensity.* Under the usual conditions of industrial radiography, the number of milliampere-minutes required for a properly exposed radiograph made with fluorescent intensifying screens increases as the x-ray intensity decreases, because of the failure of the reciprocity law.

If the milliamperage remains constant, and x-ray intensity is varied by changing the focus-film distance, the following compensating changes should be made in exposure time:

APPROXIMATE CORRECTIONS FOR RECIPROCITY LAW FAILURE

Distance Increased by	**(Direct and Lead Screen Exposures) Exposure Time Multiplied by***	**(Fluorescent Screen Exposures) Exposure Time Multiplied by***
25%	1.6	about 2
50	2.3	about 4
100	4.0	about 8
Distance Decreased by		
20%	0.62	about 0.5
33	.43	about .2
50	.25	about .1

*Column 2 shows the changes necessitated by the inverse square law only. Column 3 shows the combined effects of the inverse square law and failure of the reciprocity law.

The table above gives a rough estimate of the deviations from the simple laws given on pages 31-32, resulting from the failure of the reciprocity law for exposures with fluorescent (calcium tungstate) intensifying screens. It must be emphasized that the figures given are only approximate. The exact values of the factors will vary widely with the intensity of the fluorescent light, and with the density of the radiograph.

When distance is held constant, the milliamperage may be increased or decreased by a factor of 2, and the new exposure time calculated by the method shown on page 31, without introducing errors due to reciprocity law failure that are serious in practice.

LOGARITHMS

Since logarithms are used a great deal in the following section, a brief discussion of them is included here. A more detailed treatment will be found in some handbooks and intermediate algebra texts.

Before discussing logarithms, it will be necessary to define the term "power." The power of a number is the product obtained when it is multiplied by itself a given number of times. Thus $10^3 = 10 \times 10 \times 10 = 1000$; $5^2 = 5 \times 5 = 25$. 25 is said to be the second power of 5, or 5 raised to the second power. The figure ^{2} is known as the *exponent*. Fractional exponents are used to denote roots.

For example: $n^{\frac{a}{b}} = \sqrt[b]{n^a}$; $16^{\frac{1}{2}} = \sqrt{16} = 4$

$$10^{2.50} = 10^{\frac{5}{2}} = \sqrt[2]{10^5} = 316$$

Negative exponents indicate reciprocals of powers.

Thus: $n^{-a} = \frac{1}{n^a}$; $10^{-2} = \frac{1}{10^2} = \frac{1}{100} = 0.01$

The *common logarithm* of a number is the exponent of the power to which 10 must be raised to give the number in question. For example, the logarithm of 100 is 2. The logarithm of 316 = 2.50; the logarithm of 1000 is 3, or log 1000 = 3. It is also said that 1000 is the antilogarithm of 3, or antilog 3 = 1000.

Logarithms consist of two parts: a decimal which is always positive, called the *mantissa;* and an integer which may be positive or negative, called the *characteristic.* In the case of log 316 = 2.50, .50 is the mantissa and 2 is the characteristic. The mantissa may be found by reference to a table of logarithms, by the use of a slide rule (D and L scales), or by reference to Figure 32. No matter what the location of the decimal point may be, the logarithms of all numbers having the same figures in the same order have the same mantissa.

The characteristic of the logarithm is determined by the location of the decimal point in the number. If the number is greater than one, the characteristic is positive and its value is one *less* than the number of digits to the left of the decimal point. If the number is less than one (i. e., a decimal fraction), the characteristic is negative, and has a numerical value of one *greater* than the number of zeros between the decimal point and the first integer. A negative characteristic of, say, 2, is written $\bar{2}$. . . . to indicate that only the characteristic is negative, or 8. · · · · − 10.

From Figure 32, we see that the mantissa of the logarithm of 20 is 0.30. The characteristic is 1.

log 20 = 1.30
log 40 = 1.60
log 80 = 1.90
log 160 = 2.20
log 200 = 2.30
log 2000 = 3.30
log 20000 = 4.30
log .2 = $\bar{1}$.30 or 9.30 − 10
log .02 = $\bar{2}$.30 or 8.30 − 10

The tabulation above illustrates a very important property of logarithms. Note that when a series of numbers increases by a constant *factor* (e.g., the series 20, 40, 80, 160 or the series 20, 200, 2000, 20,000), their logarithms have a constant *difference,* in these cases, 0.30 and 1.00 respectively. In other words, a constant *increase* in the logarithm of a number means a constant *percentage increase* in the number itself.

PHOTOGRAPHIC DENSITY

Photographic density refers to the quantitative measure of film blackening. Where no danger of confusion exists, photographic density is usually spoken of merely as *density.*

Density is defined by the equation $D = \log \frac{I_o}{I_t}$ where D is density, I_o is the light intensity incident on the film, and I_t is the light intensity transmitted.

The tabulation on page 34 illustrates some relations between transmittance, per cent transmittance, and density.

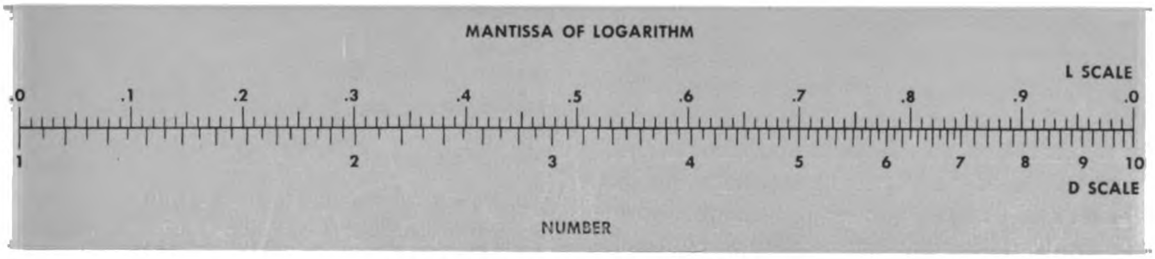


Fig. 32—Scale for determining logarithms.

Transmittance $(\frac{I}{I_o})$	%Transmittance $(\frac{I}{I_o} \times 100)$	$(\frac{I_o}{I})$	Density $(\log \frac{I_o}{I})$
1.00	100	1	0
0.50	50	2	0.3
0.25	25	4	0.6
0.10	10	10	1.0
0.01	1	100	2.0
0.001	0.1	1,000	3.0
0.0001	0.01	10,000	4.0

The above table shows that an increase in density of 0.3 reduces the light transmitted to one half its former value. In general, since density is a logarithm, a certain *increase* in density will always correspond to the same *percentage decrease* in transmittance.

Densitometers are instruments for measuring density. A number of different types, both visual and photoelectric, are on the market. For purposes of practical industrial radiography there is no great premium on high accuracy of the densitometer. A much more important property is reliability. That is, the densitometer should be able to reproduce readings from day to day.

EXPOSURE CHARTS

An exposure chart is a graph showing the relation between material thickness, kilovoltage, and exposure. In its most common form, an exposure chart resembles Figure 33. These graphs are adequate for determining exposures in the radiography of uniform plates, but serve only as a rough guide for objects having wide variations of thickness.

Exposure charts have been published and are usually available from manufacturers of x-ray equipment. However, since, in general, such charts cannot be used for different x-ray machines without the application of suitable correction factors, individual laboratories sometimes prepare their own.

A simple method for preparing an exposure chart is to make a series of radiographs of a built-up pile of plates consisting of a number of steps. This "step tablet" is radiographed at several different exposure times at each of a number of kilovoltages. The exposed films should all be processed under identical conditions and according to the procedure which will later be used for routine work. Each radiograph will consist of a series of photographic densities corresponding to the x-ray intensities transmitted by the different metal thicknesses. A certain density, for example 1.0, is selected as the basis for preparation of the chart. Wherever this density occurs on the step-tablet radiographs, there are corresponding values of thickness, milliampere-minutes, and kilovoltage. It is unlikely that many of the radiographs will contain a value of exactly 1.0 in density, but the correct thickness for this density will be found by interpolation between steps. Thickness and milliampere-minute values are plotted for the different kilovoltages in the manner shown in Figure 33.

Another method, requiring fewer step-tablet exposures but more arithmetical manipulation, is to make one step-tablet exposure at each kilovoltage. The densities in the processed step-tablet radiographs are measured. Then, from the characteristic curve of the film used, an exposure can be determined (see page 36) which would have given the chosen density (in this case 1.0) under any particular thickness of the step tablet. These values of

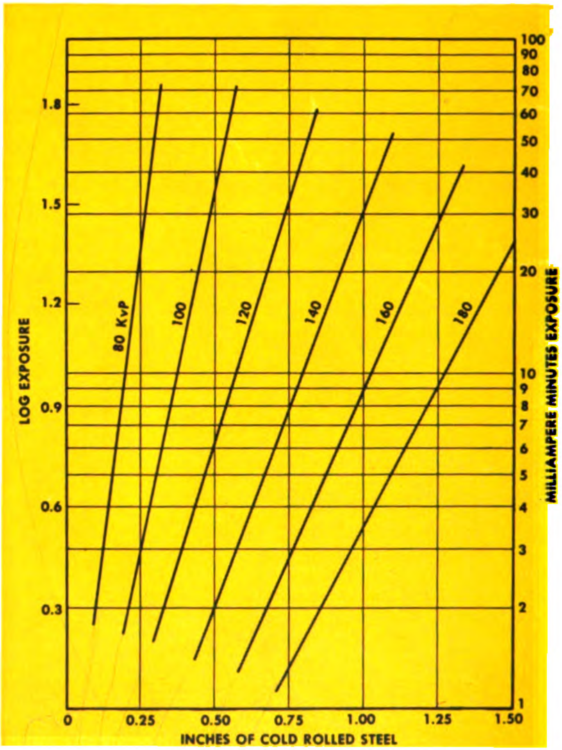


Fig. 33—Typical exposure chart for steel based on the use of *No-Screen Film* with lead foil screens at a film density of 1.0. Focus-film distance was 35 inches. Development was in *Kodak Rapid X-ray Developer* for 5 minutes at 68°F.

thickness, kilovoltage, and exposure are plotted as before.

Notice that thickness is laid off on a linear scale while milliampere-minutes are on a logarithmic scale. The logarithmic scale is not necessary but is very convenient since it compresses an otherwise long scale. A further advantage of the logarithmic exposure scale is that it usually allows the location of the points for any one kilovoltage to be well approximated by a straight line.

Any given exposure chart applies to a set of specific conditions. These fixed conditions are:

1. The x-ray machine used;
2. A certain focus-film distance;
3. A particular film type;
4. Processing conditions used;
5. The film density on which the chart is based.

Only if the conditions used in making the radiograph agree in all particulars with those used in preparation of the exposure chart can values of exposure be read directly from the chart. Any change will require the application of a correction factor. The correction factor applying to each of the conditions listed previously will be discussed independently:

1. It is sometimes difficult to find a correction factor to make an exposure chart prepared for one x-ray machine applicable to another. Different x-ray machines operating at the same nominal kilovoltage and milliamperage settings may give not only different intensities but also different qualities of radiation.

2. A change in focus-film distance may be compensated for by use of the inverse square law (page 31) or, if fluorescent screens are used, by reference to the tabulation on page 32. Some exposure charts give exposures in terms of "exposure factor" (see page 16) rather than in terms of milliampere-minutes or seconds. Charts of this type are readily applied to any focus-film distance.

3. The use of a different film type can be corrected for by referring to the table of film speeds, pages 56 and 57.

4. A change in processing conditions will cause a change in effective film speed. Therefore, if the processing of the radiographs differs from that used for the exposures from which the chart was made, the necessary correction factor must be found by experiment.

5. The chart gives exposures to produce a certain density. If a different density is required, the correction factor may be calculated from the characteristic curve of the film (see page 36).

THE CHARACTERISTIC CURVE*

The characteristic curve, sometimes referred to as the sensitometric curve or H. and D. curve (after Hurter and Driffield who, in 1890, first used it), expresses the relation between the exposure applied to a photographic material and the resulting photographic density. The characteristic curves of three typical films, *Kodak Industrial X-ray Film, Types F, A,* and *M,* exposed to direct x-rays, are given in Figure 34. Such curves are obtained by giving a film a series of known exposures, determining the densities produced by these exposures, and then plotting density against logarithm of relative exposure.

Relative exposure is used because there are no suitable units in which to express radiographic exposures. Hence, the exposures given a film are expressed in terms of some particular exposure, thus giving a relative scale. This lack of units for x-ray intensity or quantity, as applied to radiography, is no hindrance, as will be seen below. The use of the logarithm of the relative exposure, rather than the

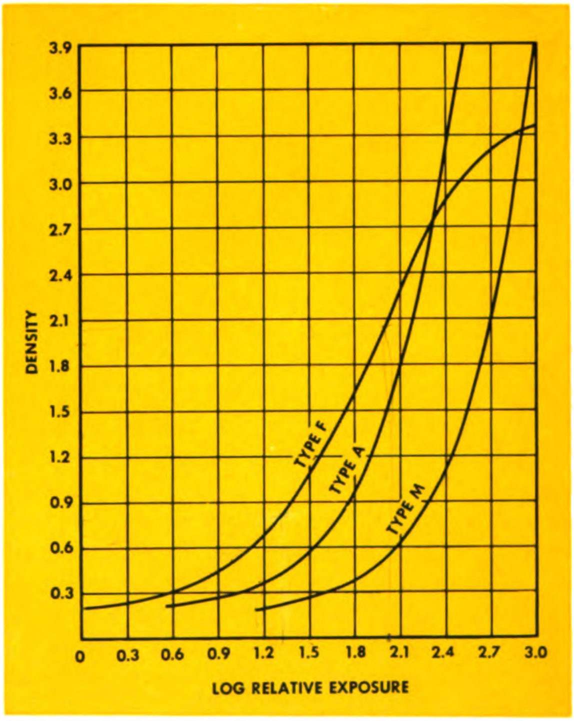


Fig. 34—Characteristic curves of *Kodak Industrial X-ray Films, Type F, Type A,* and *Type M.* Development in *Kodak Rapid X-ray Developer* at 68°F. for 5 minutes.

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*See also Appendix, pages 83-90.

relative exposure itself, has a number of advantages. It compresses an otherwise long scale. Furthermore, in radiography, ratios of exposures or intensities are usually more significant than the exposures or intensities themselves. Pairs of exposures having the same ratio will be separated by the same interval on the Log relative exposure scale, no matter what their absolute value may be. Consider the pairs of exposures given below.

Relative Exposure	Log Relative Exposure	Interval in Log Rel. Exp.
1	0.0	0.70
5	0.70	
2	0.30	0.70
10	1.00	
30	1.48	0.70
150	2.18	

This illustrates another useful property of the logarithmic scale. Referring again to Figure 32, it will be seen that the antilogarithm of 0.70 is 5, which is the ratio of each pair of exposures. Hence, to find the ratio of any pair of exposures, it is necessary only to find the antilog of the Log E interval between them. Conversely, the log exposure interval between any two exposures is found by taking the logarithm of their ratio.

As can be seen in Figure 34, the slope (or steepness) of the characteristic curves is continuously changing along the whole length of the curve. The effects of this change of slope on detail visibility are fully explained in the Appendix (pages 83 to 90). It will suffice at this point to give a qualitative outline of these effects. For example, two slightly different thicknesses in the object radiographed will transmit slightly different exposures to the film. These two exposures will have a certain small Log E (logarithm of relative exposure) interval between them, i. e., have a certain ratio. The difference in the densities corresponding to the two exposures will depend upon just where on the characteristic curve they fall, and the steeper the slope of the curve, the greater will be this density difference. Referring to Figure 34, the curve of *Type F Film*, for example, is steepest in its middle portion. This means that a certain Log E interval in the middle of the curve will correspond to a greater density difference than the same Log E interval at either end of the curve. In other words, the film contrast is greatest where the slope of the characteristic curve is greatest.

For *Type F Film*, as has been pointed out, the region of greatest slope is in the central part of the curve. For *Types A* and *M Film*, and *Eastman No-Screen Film* (see curves, page 91) the slope, and hence the film contrast, continuously increases throughout the usable density range. For *Type K Film* the slope increases up to a density of about 2.0, above which it does not change significantly within the usable density range.

Many of the common problems which arise in industrial radiography are easily solved by means of information obtained from the characteristic curve. Some specific illustrations are discussed below. In the following examples, D is used for density and Log E for logarithm of relative exposure.

Example 1

Suppose a radiograph made on *Type F Film* (see Figure 34) with an exposure of 12 milliampere-minutes has a density of 0.8 in the region of maximum interest. It is desired to increase the density to 2.0 for the sake of the increased contrast there available.

Log E at D = 2.0 is 1.97
Log E at D = 0.8 is 1.30
Difference in Log E is 0.67
Antilogarithm of this difference is 4.7

Therefore, the original exposure should be multiplied by 4.7, giving 56 milliampere-minutes to produce a density of 2.0.

Example 2

Type A Film has a higher contrast than *Type F* at D = 2.0 (see Figure 34) and also a finer grain. Suppose that, for these reasons, it is desired to make the aforementioned radiograph on *Type A Film* with a density of 2.0 in the same region of maximum interest.

Log E at D = 2.0 for *Type F Film* is 1.97
Log E at D = 2.0 for *Type A Film* is 2.16
Difference in Log E is 0.19
Antilogarithm of this difference is 1.55

Therefore, the exposure for D = 2.0 on *Type F Film* should be multiplied by 1.55, giving 87 milliampere-minutes, to give D = 2.0 on *Type A Film*.

Example 3

Suppose that a certain specimen is radiographed on *Type A Film* so that the maximum density is 1.2 and the minimum density is 0.4. The slope of the characteristic curve at D = 0.4 is too low to give adequate radiographic contrast and, for this reason, it is desired to increase the minimum density to 1.0. The required increase in exposure can be found by the method of Example 1. The question then arises as to whether the maximum density obtained with this new exposure will be too high to view on the available illuminators.

Log E for D = 1.20 is 1.91

Log E for D = 0.40 is 1.27

Difference in Log E is 0.64

So long as the kilovoltage remains the same, this Log E interval will always separate the exposures under the two parts of the specimen.

Log E for D = 1.0 is 1.81

Difference in Log E is 0.64

Log E for maximum density in new exposure is 2.45

The density corresponding to this Log E is 3.5.

Example 4

According to the exposure chart, page 34, 9 milliampere-minutes will give a density of 1.0 on *No-Screen Film* through 1¼-inch steel at 180 kilovolts. If 1¼ inches is the maximum thickness in the specimen, the other densities will be higher than 1.0. It may be desirable, before making the exposure, to ascertain the density that will be produced under some other part of the specimen. Consider a section 1 inch thick. It will be given the same exposure (9 milliampere-minutes) as the 1¼-inch section, but, according to the exposure chart requires but 3.4 milliampere-minutes to produce a density of 1.0.

Therefore, the ratio of the exposure actually given to that required to produce D = 1.0 is: $\frac{9.0}{3.4} = 2.6$. The logarithm of this ratio is 0.42.

Referring to the characteristic curve for *No-Screen Film* (page 95), it is found that an increase of 0.42 beyond the Log E required to produce a density of 1.0 gives a Log E of 1.02 + 0.42 or 1.44, which corresponds to a density of 2.1.

ESTIMATING EXPOSURES FOR MULTI-THICKNESS SPECIMENS

A minimum acceptable density for radiographs is often specified. This is not because of any virtue in the particular density, but because below a certain point the slope of the characteristic curve, and hence the film contrast, is too low for adequate rendition of detail. Similarly, a maximum acceptable density is often designated either because, as with *Type F Film*, the film contrast again falls off at high densities, or because detail in densities above a certain value cannot be seen on the available illuminators.

The problem of radiographing a part having several thicknesses resolves itself into one of using the available density range most efficiently. In other words, the kilovoltage and exposure should be so adjusted that the image of the thinnest part has the maximum acceptable density, and the thickest has the minimum. Exposure charts alone, although they are adequate for application to the radiography of uniform plates, can serve only as rough guides

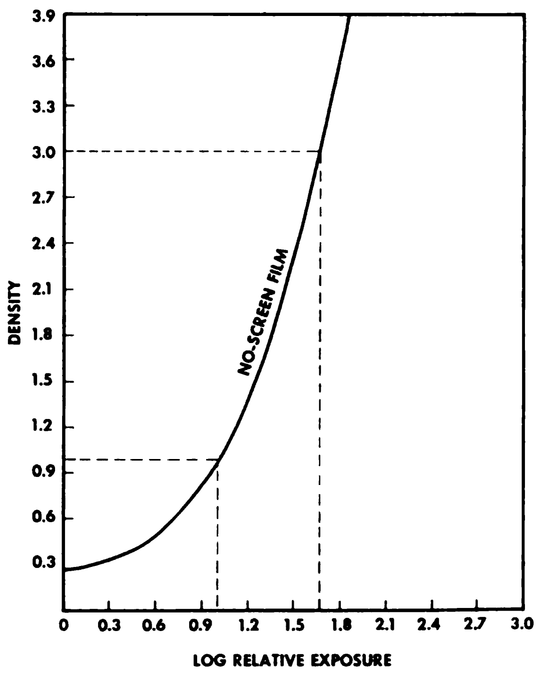

Fig. 35—Characteristic curve for *Eastman No-Screen X-ray Film*, developed in *Kodak Rapid X-ray Developer* for 5 minutes at 68°F. Dotted lines show how the log E (logarithm of relative exposure) interval corresponding to a certain density interval may be found.

for articles having considerable variation in section. Previous experience, of course, is a guide but, even when a usable radiograph has been obtained, the question remains as to whether or not it is the best possible.

A quantitative method of finding such exposures combines information derived from both the exposure chart and the characteristic curve of the film used. The procedure is outlined below:

Assume that 1.0 is the lowest acceptable density on *No-Screen Film*, and that 3.0 is the highest. As shown in Figure 35, this density interval corresponds to a certain log exposure interval, in this case, 0.64.

The antilog of 0.64 is 4.4, which means that 4.4 times as much exposure is required to produce a density of 3.0 as of 1.0. It is therefore desired that the thinnest portion of the object to be radiographed transmit just 4.4 times as much radiation as the thickest part, so that with the proper adjustment of the radiographic exposure, all parts of the object will be rendered within the density range 1.0 to 3.0. The ratios of x-ray intensities transmitted by different portions of the object will depend upon the kilovoltage; and by examination of the exposure chart of the x-ray machine, the proper choice of kilovoltage can be made. For example, in the chart of Figure 36, the 180 kilovolt line shows that a thickness range of ⅞ to 1¼ inches of steel corresponds to an exposure ratio of 9.3 milliampere-minutes to 2.1 milliampere-minutes, or 4.4, which is the ratio required. The next problem is to determine the radiographic exposure for this case. The chart of Figure 36 gives the exposure to produce a density of 1.0 on *No-Screen Film*. Since it is desired to produce a density of 1.0 under the thick section (1¼ inches) the exposure in this case would be 9.3 milliampere-minutes.

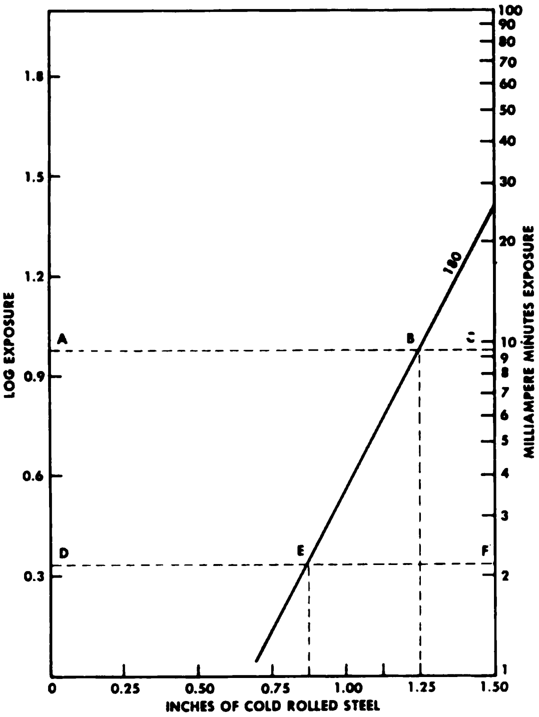

Fig. 36—Abridged form of exposure chart shown in Figure 33 illustrating a metal thickness interval corresponding to the log E interval of Figure 35. If the separation of lines ABC and DEF is maintained, they may be moved up and down the chart. They will then mark off a large number of thickness ranges on the various kilovoltage lines, all of which will completely fill the density range which has been assumed to be useful.

A simple means of applying this method to routine work is as follows:

Parallel lines are drawn on a transparent cellulose acetate sheet such as a fixed-out x-ray film in the manner shown in Figure 37. The spacing between the base line and the line immediately above is the log relative exposure interval for *No-Screen Film* between D=1.0 and D=3.0. *It is laid off to the same scale as the ordinate scale of the exposure chart.* Similarly, the distance from the base line to any other line parallel to it can be made to correspond to the log relative exposure interval for other density limits and films. This transparent guide is moved up and down on the exposure chart with its lines parallel to the thickness axis. The two guide lines being used form a rectangle with the two vertical lines of the exposure chart which mark the thickness limits of the specimen. The correct kilovoltage is the one the graph of which intersects diagonally opposite corners of the rectangle. If the film type used is the one for which the chart was prepared, the correct exposure is indicated at the intersection of the upper guide line with the exposure scale (Point C in Figure 36). If a different film is used, a suitable correction factor obtained either from the table, pages 56-57, or by the method of Example 2, page 36, must be applied to the exposure as read from the chart.

Since there is but one graph on a gamma-ray exposure chart, this procedure will indicate limiting thicknesses of material which can be radiographed within the prescribed density limits.

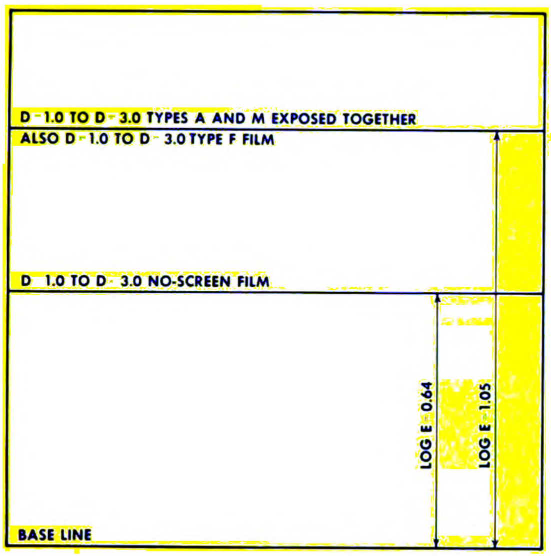
D = 1.0 TO D = 3.0 TYPES A AND M EXPOSED TOGETHER
ALSO D = 1.0 TO D = 3.0 TYPE F FILM
D = 1.0 TO D = 3.0 NO-SCREEN FILM
LOG E = 0.64
LOG E = 1.05
BASE LINE

Fig. 37—System of lines drawn on a transparent sheet to be used in connection with an exposure chart for estimating radiographic exposures for multi-thickness specimens.

If the chart shows that the thickness range is too great for a single exposure under any condition, it may be used to select two different exposures to cover the range. Another way is to load the cassette with two films of different "speed" and expose them simultaneously. Here again, the chart may be used to select the technic. The log relative exposure range for two films of different speed, when used together in this manner, is the log exposure difference between the value at the low-density end of the faster film curve and the high-density end of the slower film curve. Referring to Figure 34 and assuming the use of film *Types A* and *M*, the result is 1.05, which is the difference between 1.80 and 2.85. It is necessary, of course, that the films be close enough together in speed so that they will have some "overlap" on the Log E axis.

Several factors in the procedure outlined have a direct influence on the accuracy with which exposures can be predicted. Exposure charts are prepared ordinarily by radiographing some kind of step tablet. Since the proportion of scattered radiation depends upon thickness of material and therefore upon the distribution of the material in a given specimen, there is no assurance that the scattered radiation under different parts will correspond to the amount under the same thicknesses of the step tablet. In fact, it seems unreasonable to expect exact correspondence between scattering conditions under two objects whose thicknesses are the same but in which the distribution of material is quite different. Naturally, the more closely the distribution of metal in the tablet resembles that in the specimen, the more accurately will the exposure chart serve its purpose. For example, a narrow tablet would approximate the scattering conditions for specimens containing narrow bars.

Films from which characteristic curve data are obtained should be processed under the same (or equivalent) conditions as the radiographic films. Time, temperature, and degree of exhaustion and agitation of developer are all variables which affect the shape of the characteristic curve and should therefore be standardized. When temperature or amount of exhaustion of developer does not correspond to the original conditions, proper compensation can be made by changing the time according to schedules available. This method for estimating exposures will yield the most reliable results when care is taken with details of processing.

FACTORS AFFECTING SENSITIVITY

RADIOGRAPHIC SENSITIVITY

RADIOGRAPHIC CONTRAST

SUBJECT CONTRAST

Affected by:

A Thickness differences in specimen

B Radiation quality
(See pp. 17, 28, 41, 42)

C Scattered radiation
(See pp. 25-30)

Reduced by:

- **1** Masks and diaphragms
  (See p. 26)
- **2** Filters
  (See pp. 27-29)
- **3** Lead screens
  (See pp. 19, 20, 29)
- **4** Potter-Bucky diaphragm
  (See p. 29)

FILM CONTRAST

Affected by:

A Type of film
(See pp. 56-58, 87, 89),
Curves pp. 91-97

B Development time, temperature, and agitation
(See pp. 67-70)

C Density
(See pp. 35, 36, 89, 90)

D Degree of exhaustion of developer
(See pp. 70-72)

DEFINITION

GEOMETRICAL FACTORS

(See pages 9-12)

Affected by:

A Focal spot size
(See pp. 9-11)

B Focus-film distance
(See pp. 9-11)

C Specimen-film distance
(See pp. 9-11)

D Abruptness of thickness changes in specimen
(See pp. 43, 44)

E Screen-film Contact
(See pp. 20, 22, 23)

GRAININESS FACTORS

Affected by:

A Type of film
(See pp. 43, 56-58)

B Type of screen
(See pp. 19, 21, 23, 43)

C Radiation quality
(See p. 43)

SENSITIVITY AND DETAIL VISIBILITY

SINCE the purpose of most radiographic inspections is to examine a specimen for inhomogeneities, a knowledge of the factors affecting the visibility of detail in the finished radiograph is essential. The following outline shows the relationships of the various factors influencing radiographic sensitivity, together with page references to the discussion of individual topics. For convenience, a few important definitions will be repeated here.

Radiographic contrast between two areas of a radiograph is the difference between the densities of those areas. It depends upon both subject contrast and film contrast.

Subject contrast is the ratio of x-ray intensities transmitted by two selected portions of a specimen. Subject contrast depends upon the nature of the specimen, the radiation quality used, and the intensity and distribution of the scattered radiation, but is independent of time, milliamperage, and distance, and of the characteristics or treatment of the film used.

Film contrast refers to the slope (steepness) of the characteristic curve of the film. It depends upon the type of film, the processing it receives, and the density. It is independent, for practical purposes, of the quality and distribution of the radiation reaching the film.

Definition refers to the sharpness of outline in the image.

SUBJECT CONTRAST

On page 17, it was pointed out that subject contrast decreases as kilovoltage is increased. The decreasing slope (steepness) of the lines of the exposure chart (Figure 33, page 34) with increasing kilovoltage illustrates this lowering of subject contrast as the radiation becomes more penetrating. For example, consider a steel part containing two thicknesses, ¾ inch and 1 inch, which is radiographed at 140 KvP and 180 KvP. In the table above, column 3 shows the exposure in milliampere-minutes required to reach a density of 1.0 through each thickness at each kilovoltage. These data are from Figure 33. It is apparent that the milliampere-minutes required to produce a given density at any kilo-

KvP	Thickness	Exposure to give D = 1.0	Relative Intensity	Ratio of Intensities
140	¾″	7.9 min.	3.9	3.9
	1″	31.0	1.0	
180	¾″	1.4	22.0	2.5
	1″	3.5	8.9	

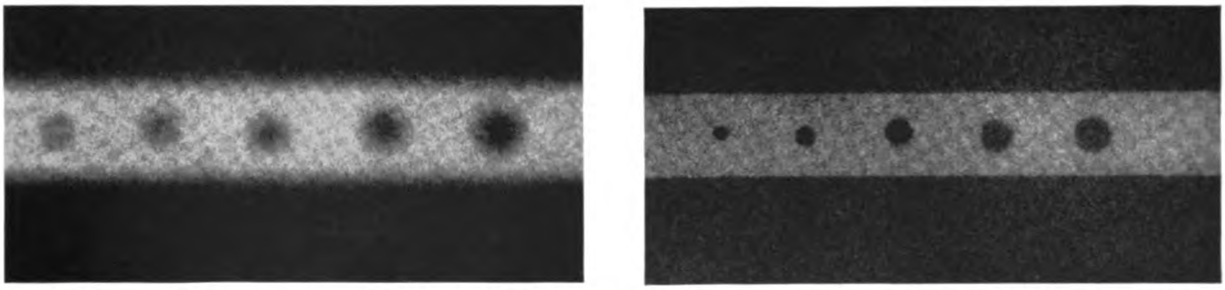

Fig. 38—Advantage of higher radiographic contrast on left is largely offset by poor definition. Despite lower contrast (right) better rendition of detail is obtained by improved definition.

voltage are inversely proportional to the corresponding x-ray intensities passing through the different sections of the specimen. Column 4 gives these relative intensities for each kilovoltage. Column 5 gives the ratio of these intensities for each kilovoltage.

Column 5 shows that, at 140 kilovolts, the x-ray intensity passing through the ¾-inch section is 3.9 times as great as that passing through the 1-inch section. At 180 kilovolts, the radiation through the thinner portion is only 2.5 times that through the thicker. Thus, as the kilovoltage increases, the ratio of x-ray transmission of the two thicknesses grows less, indicating a lower subject contrast.

FILM CONTRAST

The dependence of film contrast upon density must be kept in mind when considering problems of radiographic sensitivity. In general the contrast of radiographic films, except those designed for use with fluorescent screens, increases continuously with density in the usable density range. (See Appendix, page 87 and curves, page 91.) Therefore, for films which exhibit this continuous increase in contrast, the best density, or upper limit of density range, to use is the highest that can conveniently be viewed with the illuminators available. Adjustable high-intensity illuminators which greatly increase the maximum density that can be viewed are commercially available.

The use of high densities has the further advantage of increasing the range of x-ray intensities which can be usefully recorded on a single film. This in turn permits the use of lower kilovoltage, with resulting increase in subject contrast and radiographic sensitivity.

The screen-type films have their maximum contrast at a density of about 2.0 (see pages 87 and 88). This means that, other things being equal, the greatest radiographic sensitivity will be obtained when the exposure is adjusted to give this density.

GRAININESS

The image on an x-ray film is formed by countless minute silver grains, the individual particles being so small as to be visible only under a microscope. However, these small particles group together in relatively large masses. This "clumping," which is quite visible to the naked eye or with a magnifica-

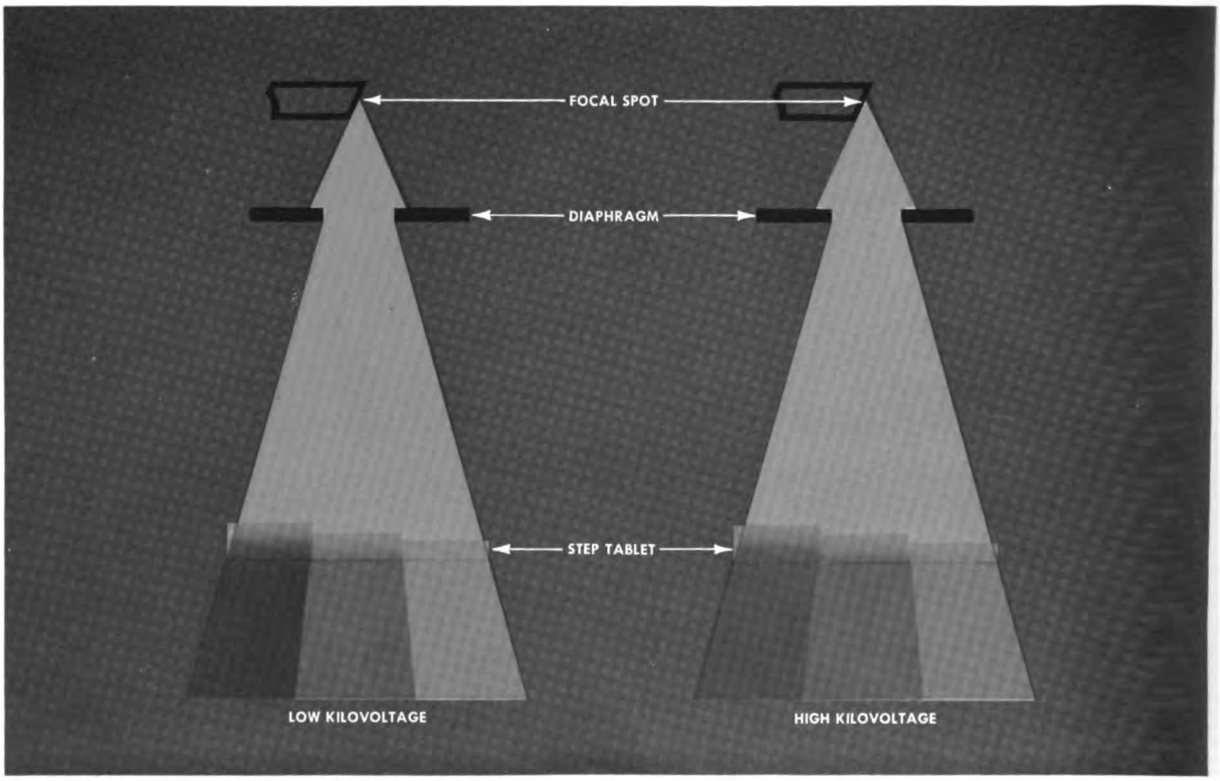

Fig. 39—With the same subject, the lower kilovoltage beam produces a higher subject contrast (left) than the higher kilovoltage beam (right).

tion of only a few diameters, produces the visual impression which is called *graininess.*

All films exhibit graininess to a greater or lesser degree. In general, it may be said that the slower films have less graininess than the faster. Thus, *Type K Film* is more grainy than *Type A*.

The graininess of all films increases as the penetration of the radiation increases, although the rate of increase of graininess may be different for different films. Hence, it is possible that of two film types, one will be the more grainy at a low kilovoltage, and the other show greater graininess at a high kilovoltage. The graininess of the images produced at high kilovoltages makes the inherently fine-grain films, such as *Types A* and *M*, especially useful in the 1000- to 2500-kilovolt range.

Graininess is but slightly affected by processing conditions. If the processing technic is adjusted to compensate for changes in temperature or developer formula or activity, it will be found that these factors have little effect on graininess. In general, graininess is a film property. A developer which gives an appreciable decrease in graininess also gives an appreciable loss in film speed.

Another source of graininess is encountered in radiography with fluorescent intensifying screens. The graininess of fluorescent screens increases markedly with increased hardness of radiation. It is this fact which limits the use of fluorescent screens at high kilovoltages and with gamma rays.

Lead foil screens have little effect on graininess, although careful tests indicate that an exposure with lead foil screens has very slightly greater graininess than a direct exposure at the same kilovoltage and density.

PENETRAMETERS

As a check on the adequacy of the radiographic technic, it is customary to place a standard test piece, called a *penetrameter*, on the tube side of the specimen. In its simplest form, the penetrameter may consist of a small strip of the same material as the specimen itself, but having a thickness of a definite proportion, say 2 per cent, of the thickness of the specimen. The radiographic technic is considered satisfactory if the outline of the penetrameter shows clearly in the radiograph. In this case, the radiographic procedure has been able to demonstrate a 2 per cent difference in specimen thickness, and the *penetrameter sensitivity* is said to be 2 per cent or better. Thus a *low* percentage value represents *high* sensitivity and vice versa. Ordinarily, 2 per cent penetrameter sensitivity is considered satisfactory, but for some purposes a lower percentage is desired, while in other classes of work 5 per cent may be acceptable.

Another form of penetrameter may consist of a step wedge of the material, and the sensitivity is determined from the thinnest layer that can be distinguished in the radiograph. Penetrameters may also contain holes of various diameters and judgment is based upon the radiographic rendition of the holes. Inspection codes for the various products or structures may specify the type of penetrameter to be employed.

It should be remembered that even if a certain hole in a penetrameter is visible on the radiograph, a cavity of the same diameter and thickness may be invisible. The penetrameter holes, having sharp boundaries, give an abrupt, though small, change in metal thickness while a natural cavity with more

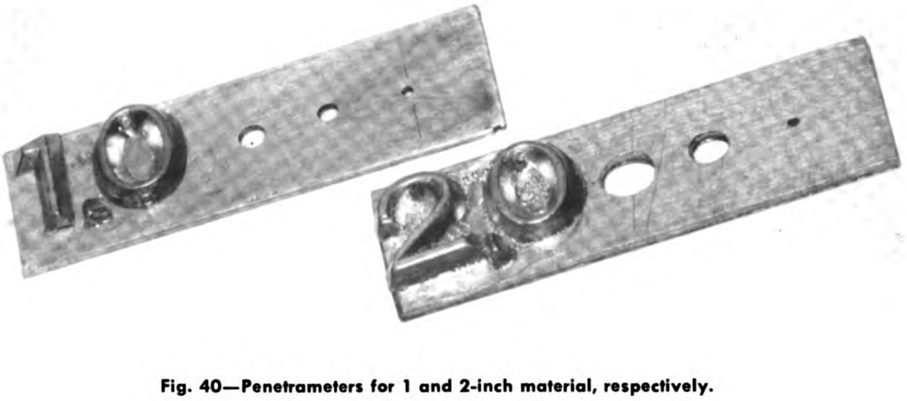

Fig. 40—Penetrameters for 1 and 2-inch material, respectively.

or less rounded sides gives a gradual change. Therefore, the image of the penetrameter hole will be sharper and more easily seen in the radiograph than the image of the cavity. Similarly, a fine crack may be of considerable extent, but if the x-rays happen to pass from tube to film along the thickness of the crack, its image on the film may well be invisible because of the very gradual transition in photographic density. Thus, a penetrameter is used to indicate the quality of the radiographic technic and not as a measure of the size of cavity which can be shown.

VIEWING AND INTERPRETING RADIOGRAPHS

The examination of the finished radiograph should be made under conditions which favor the best visualization of detail combined with a maximum of comfort and minimum of fatigue for the observer. To be satisfactory for use in viewing radiographs, an illuminator must fulfill the following requirements: first, it must provide light of an intensity that will illuminate the average density areas of the radiographs to their best advantage, free from glare; second, it must diffuse the light evenly over the entire viewing area. The color of the light is of no optical consequence, but most observers prefer bluish-white. The *Kodak Coldlight X-ray Illuminator* meets all of these demands, and, in addition, its design is such that it promotes efficiency, economy, and comfort.

Where a somewhat higher intensity is needed, a *Kodak Coldlight X-ray Illuminator* may be fitted with two 18″ T-8, 15-watt *green fluorescent* tubular lamps. These light sources have a higher luminous output than the "daylight" type with the same electrical input.

The Eastman X-ray Illuminator, Model D, shown in Figure 41, will accommodate individual radiographs up to 8″ x 10″. A similar illuminator called the *Kodachrome Illuminator, Model A,* has a 10″ x 10″ viewing area.

For the routine viewing of high densities, one of the commercially available high-intensity illuminators should be used. These illuminators provide an adjustable light source, the maximum intensity of which is high enough to allow densities in the neighborhood of 4.0 to be viewed.

Such a high-intensity illuminator is especially useful for the examination of radiographs of objects having a wide range of thicknesses, resulting in a correspondingly wide range of densities in the radiograph. If the exposure has been adequate for the greatest thickness in the specimen, the detail reproduced in other thicknesses can usually be visualized with illumination of sufficient intensity.

The contrast sensitivity of the human eye (i. e., the ability to distinguish small brightness differences) is greatest when the surroundings are of about the same brightness as the area of interest. Thus, to see the finest detail in a radiograph, the illuminator must be masked to avoid glare from bright light coming around the edges of the radiograph, or through areas of low density. Further, subdued lighting, rather than total darkness, is preferable in the viewing room. The room illumination must be so arranged that there are no reflections from the surface of the film under examination.

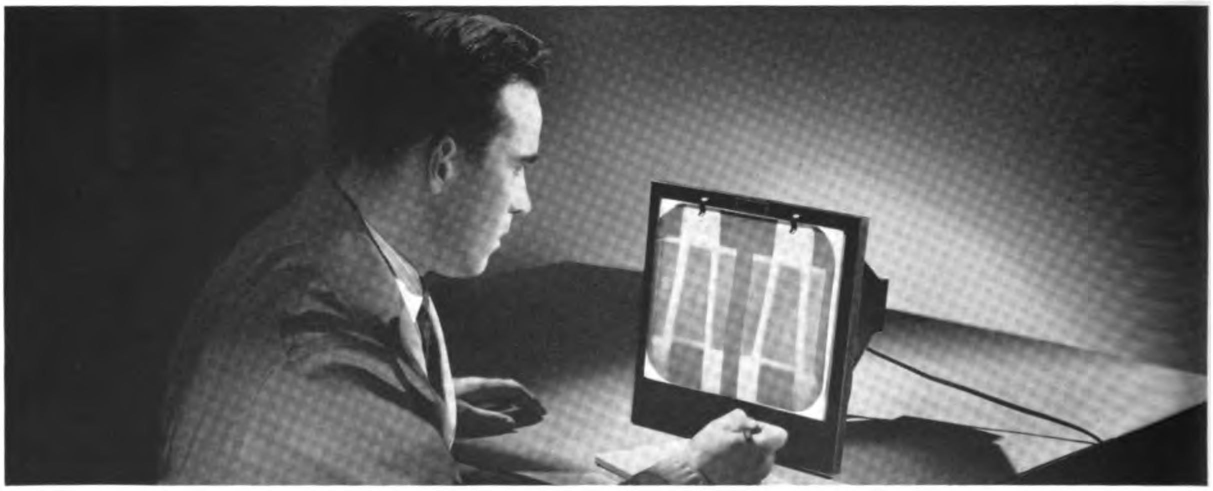

Fig. 41—Viewing radiograph on 8″ x 10″ Illuminator.

SPECIAL TECHNICS

MICRORADIOGRAPHY

Sometimes, usually with thin specimens of low x-ray absorption, the detail required for study is too fine to be seen with the naked eye, and examination of the image through a low-powered microscope, or enlargement of the radiograph by ordinary optical projection, is required to visualize the available detail. This method, *microradiography*, generally employs soft x-rays, generated in the range of 5 to 50 KvP. The photographic emulsion is usually single-coated and must be much finer-grained than ordinary x-ray films.

Commercial applications of microradiography have included such unrelated subjects as the study of cemented joints in corrugated cardboard, and distinguishing between natural and cultured pearls. Biological materials, such as tissue sections, insects, and seeds, have been usefully examined. In horticulture, the distribution of inorganic spray materials on foliage has been investigated with the aid of microradiography. Of particular interest to the metallurgist is the demonstration of the segregation of the constituents of an alloy in a thin section.

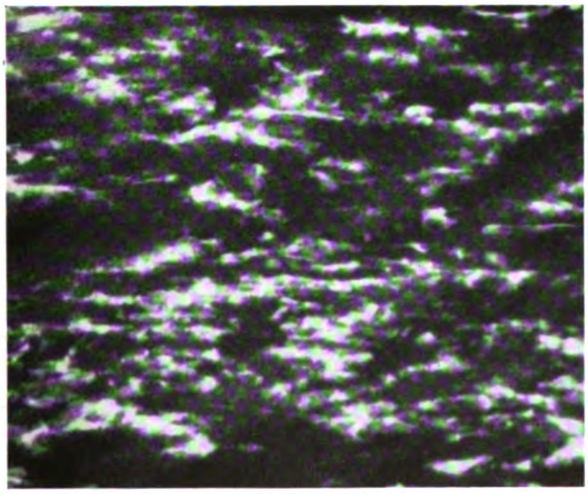

Fig. 42—Microradiograph of 24ST alloy, made on Eastman Spectroscopic Plate, Type 548-O. Enlargement is 200 diameters.

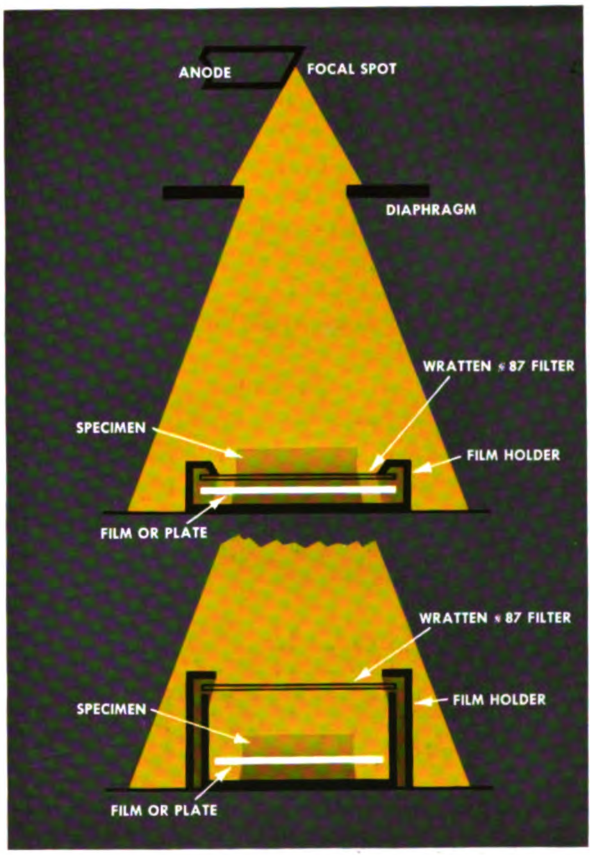

Fig. 43—Possible arrangements of specimen, film, and film holder for microradiography. The specimen thickness and its separation from the film have been exaggerated for illustrative clarity.

The window of the x-ray tube should be highly transparent to the soft x-rays used. A window of thin beryllium, or one consisting of an inverted bubble of glass about 20 microns thick, is very satisfactory. The tube should, preferably, be watercooled, and a small focal spot is advantageous with specimens of appreciable thickness.

It is necessary to prepare a special film or plate holder (see Figure 43), with a window or cover that will not cast a shadow of its structure on the photographic surface. Black paper is generally unsuitable, particularly at the lower kilovoltages. A gelatin filter opaque to blue light, such as the *Wratten No. 87*, is recommended. Two layers of this filter may be needed if the exposure room is brightly lighted, or if there is considerable light from the tube filament. Another arrangement is to mount the specimen directly in contact with the photographic surface and enclose both specimen and film (or plate) in a lighttight box with a suitable window made of *Wratten No. 87 Filter* for the entrance of the x-rays (see Figure 43).

This filter material is properly identified as *Gelatin Film Filter*, *Wratten No. 87* and in ordering, desired size should be stated. Maximum size available is 11″ x 18″.

The focus-film distance usually ranges from 3 to 12 inches. The choice of tube voltage must be adjusted to the character of the specimen and may be quite critical if the finest quality radiographic results possible are to be obtained from a particular specimen.

The type of film or plate must be selected to meet the degree of magnification to be used in examining the radiograph. The following photographic materials are suggested for this work; the relative speeds, and the degree of magnification permissible with each, are indicated. (*Kodak Rapid X-ray Developer*, 5 minutes, 68°F.)

PHOTOGRAPHIC MATERIALS FOR MICRORADIOGRAPHY

Material	Relative Speed	Approximate Maximum Enlargement* (Diameters)
Kodak Industrial X-ray Film, Type M	100	12
Eastman Spectroscopic Plate, Type V-O	40	35
Kodalith Halftone	4	50
Eastman Spectroscopic Plate, Type 548-O	0.2	200

*Extremely good contact between specimen and photographic material is necessary if these magnifications are to be achieved.

It is hardly practicable to specify exact exposure technics in microradiography, but the following example may serve as a useful guide: specimen, plate of aluminum-base alloy, ¼ mm. thick; exposure, 20 KvP, 25 milliamperes, 12-inch focus-film distance, time, 6 minutes; film, Kodalith Halftone.

Because of the relatively high absorption by air of the very soft x-radiation used in microradiography, the x-ray intensity will decrease with distance from the focal spot more rapidly than calculations based on the "inverse square" law would indicate. (See page 31.)

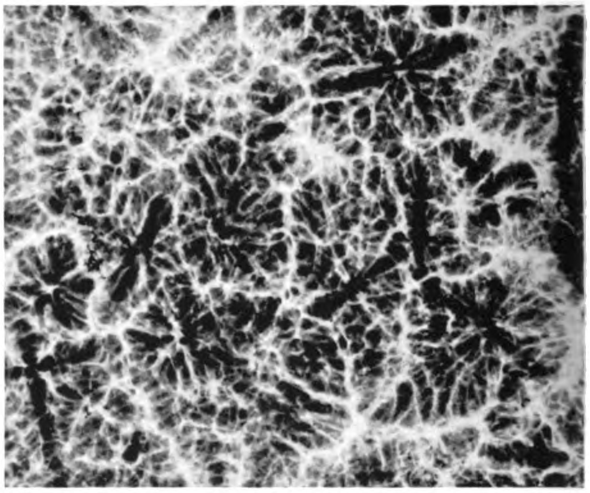

Fig. 44—Microradiograph of cast aluminum alloy containing about 8% copper. Made on Eastman Spectroscopic Plate, Type 548-O. Light areas are the copper-rich regions. Enlargement is 35 diameters.

FLUOROSCOPY

Fluoroscopy differs from radiography in that the x-ray image is observed visually on a fluorescent screen rather than recorded on a film. Figure 45 shows a diagrammatic sketch of an industrial fluoroscopic unit.

The fluoroscopic method has the advantages of high speed and low cost.

The limitations of fluoroscopy are three: (1) Examination of thick, dense, or high atomic number specimens is impractical, since the x-ray intensities passing through such specimens are too low to give a sufficiently bright image on the fluorescent screen. (2) The sensitivity of the fluoroscopic process is not as great as that of radiography, 5 per cent perhaps being the best that can be expected routinely.

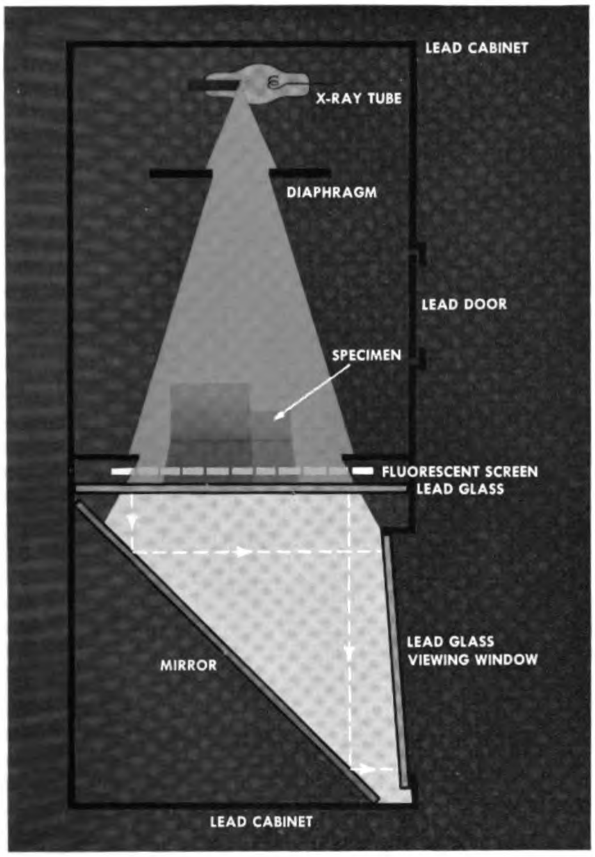

Fig. 45—Schematic diagram of an industrial fluoroscope. Commercial models may differ from the illustration. For more rapid examinations industrial fluoroscopes may be provided with material conveyors.

This is due in part to the lower contrast and coarser grain of the fluoroscopic screen as compared to the film record, and in part to the relatively short focus-screen distances which must be used to obtain high screen brightnesses. This latter factor also increases the distortion of the fluoroscopic image. (3) The lack of a permanent record of the examination may be a further disadvantage.

From the foregoing, it can be seen that the main field for fluoroscopy is in the rapid examination of light, easily penetrated articles whose unit value does not warrant the expense of radiography, or of items for which a highly sensitive test is unnecessary. Fluoroscopy has been used, for example, in the inspection of packaged foods for foreign bodies, and of molded plastic parts for correct placement of metallic inserts. In some cases, it has been found advantageous to sort parts fluoroscopically before they are radiographed, in order to save the expense of testing specimens which have gross flaws.

PHOTORADIOGRAPHY

In photoradiography, the image on the fluorescent screen is photographed with a camera on small or even miniature film rather than viewed directly. In the medical field, the economy of this procedure has made it applicable to the examination of large groups of people for finding cases of tuberculosis. In rendition of detail, photoradiography is superior to fluoroscopy largely because the film can be viewed with ample illumination and in part because the photographic process enhances the contrast of the fluorescent image.

Compared to full-sized radiography, the factors which diminish detail in the miniature photoradiograph are the graininess of the fluorescent screen, the limitations of the lens in definition, and the relatively greater influence of film graininess in the small image. Since the requirements of medical and industrial radiography are not the same, photoradiographic units for each application may be expected to differ from one another in many details.

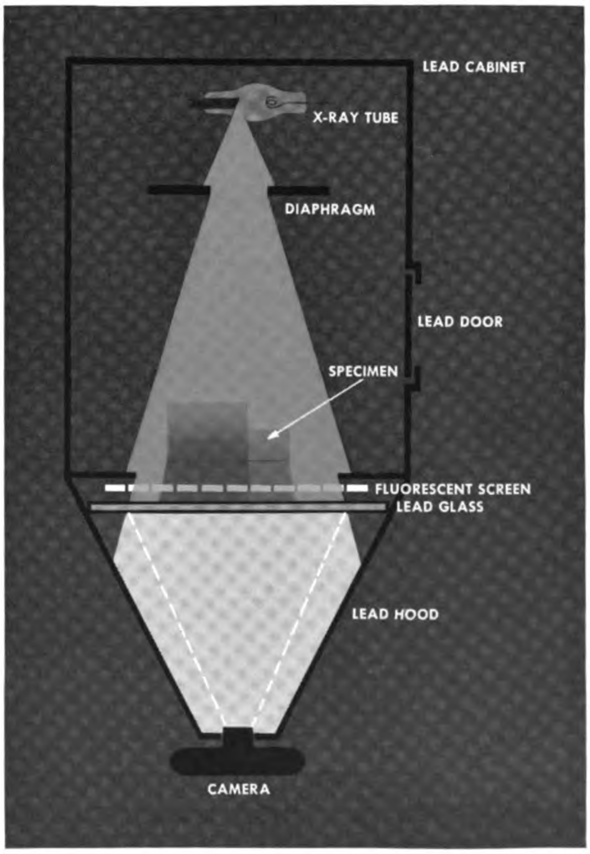

Fig. 46—Schematic diagram of an industrial photoradiographic unit. Details of commercial units may differ from the illustration.

In the industrial field, photoradiography has been used in a number of instances for the inspection of parts for which the sensitivity requirements are not severe, and where the value of the part is too low to permit the expense of conventional radiography. It is too early, perhaps, to judge the extent to which this method will prove useful in the examination of materials.

HIGH-SPEED RADIOGRAPHY

Exposure times as short as one-millionth of a second may be achieved by the use of specially designed high-voltage generating equipment and x-ray tubes. Such exposure times are sufficiently short to "stop" the motion of projectiles, high-speed machinery, and the like (see Figures 47 and 48).

This apparatus differs from the usual industrial x-ray equipment in design of both high-voltage generator and x-ray tube. The generator is one in which large high-voltage condensers are suddenly discharged through the x-ray tube, giving a high-voltage pulse of very short duration. The x-ray tube has a cold cathode rather than the conventional heated filament. The emission from this cold cathode is initiated by means of a third electrode placed near it. Once the electron emission has started, the discharge immediately transfers to the target which is of conventional design. The tube current may reach values as high as 2000 amperes (2 million milliamperes), but because of the extremely short times of exposure, the focal spot load is not excessive.

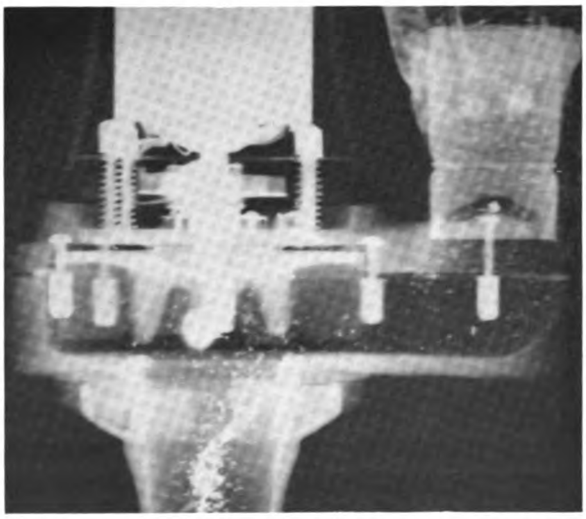

Fig. 47—High speed radiograph of lead particles passing through a vacuum cleaner. Exposure time 0.000001 sec.

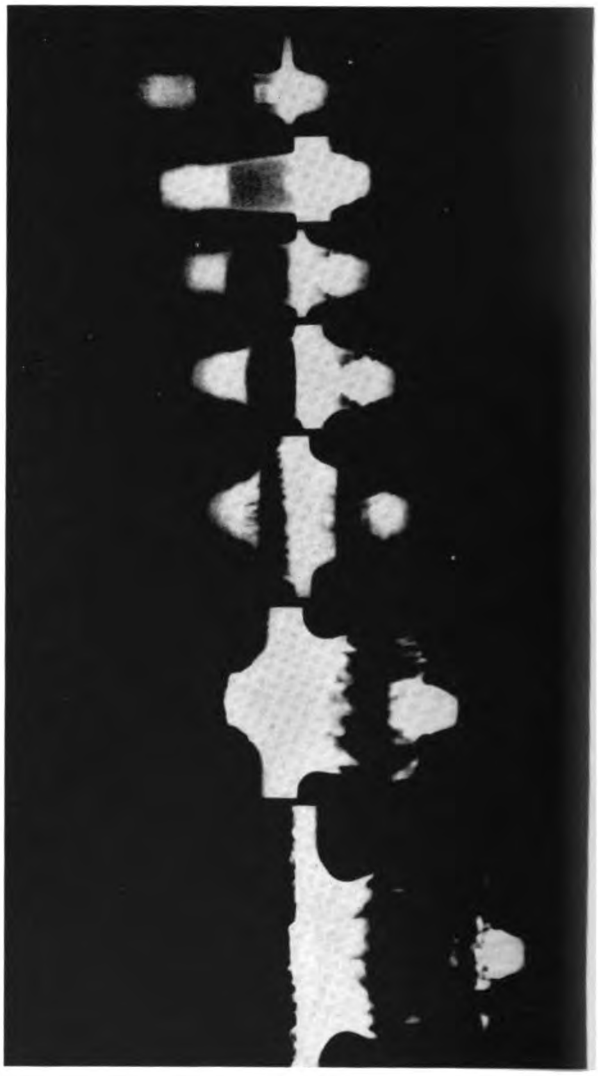

Fig. 48—High speed x-ray pictures of the functioning of 20mm. HEI shell.

DEPTH LOCALIZATION OF DEFECTS

Two general methods are available for determining the depth of a flaw within a specimen. The chief value of stereoradiography lies in giving a vivid three-dimensional view of the subject, although with the aid of auxiliary procedures it can be used for the actual measurement of depth. A more convenient scheme for depth measurement is the parallax method, in which, after making two exposures from two positions of the x-ray tube, the depth of a flaw is computed from the shift in the shadow of the flaw. Stereoradiography and the parallax method are essentially alike in principle but are carried out in different ways.

Stereoradiography

Objects viewed with a normal pair of eyes appear in their true perspective and in their correct spatial relation to each other largely because of man's natural stereoscopic vision; each eye receives a slightly different view and the two images are combined by the brain to give the impression of three dimensions.

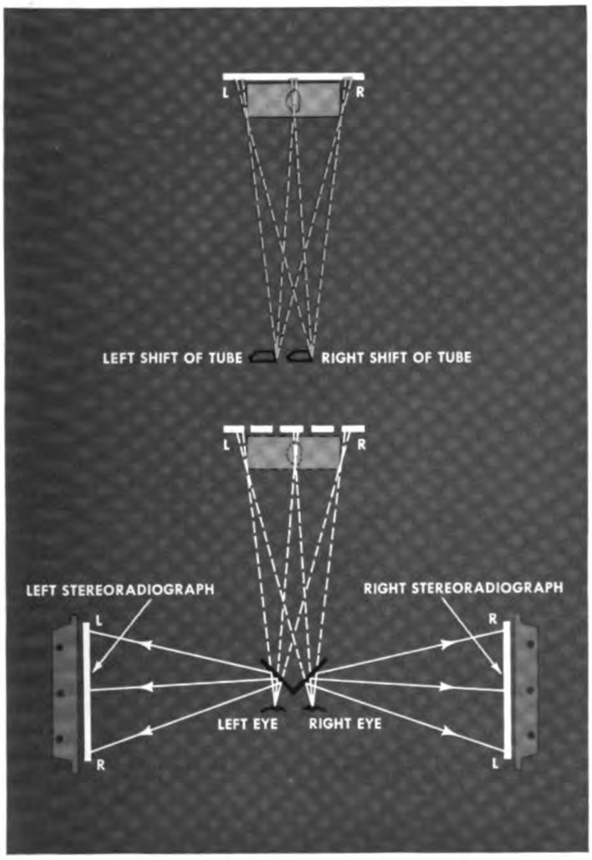

Fig. 49—Schematic diagrams showing the methods of making and viewing stereoradiographs.

A single radiographic image does not possess perspective. Therefore, it cannot give the impression of depth, or indicate clearly the relative positions of various parts of the object along the direction of vision. The stereoscopic method, designed to overcome this deficiency of a single radiograph, requires two radiographs made from two positions of the x-ray tube, separated by the normal interpupillary distance. They are viewed in the Wheatstone type of stereoscope, a device in which two plane mirrors, set at an angle to each other midway between two facing illuminators, present the reflected image of the stereoradiographs. Each eye sees only one image, but, as in ordinary vision, the brain fuses the two images into one in which the various parts stand out in striking relief in their true perspective and in their correct spatial relation.

The radiograph exposed in the right-shift position of the x-ray tube is viewed by the right eye, and the one exposed in the left-shift position is viewed by the left eye. In fact, the conditions of viewing the radiographs should be exactly analogous to the conditions under which they were exposed; the two eyes take the place of the two positions of the focal spot of the x-ray tube, and the radiographs, as reflected in the mirrors, occupy the same position with respect to the eyes as did the films with respect to the tube during the exposures. The eyes see the x-ray representation of the part just as the x-ray tube "saw" the actual part (Figure 49).

Since the mirrors of the Wheatstone-type stereoscope reverse the image from right to left, the radiographs must be reversed from right to left when they are mounted over the illuminators, so that the tube side of the images will be reflected in the mirrors and identification data can be read correctly.

The stereoscopic impression is much more distinct if the specimen has a well-defined structure extending throughout its volume. If such a structure does not exist, as, for example, in a flat plate of homogeneous material, it is necessary to provide such a structure on one or more surfaces of the specimen. A wire mesh of wide spacing mounted on both the front and rear surfaces of the specimen will generally suffice, or a similar pattern can be applied in the form of crosslines of lead paint. In stereoscopic radiographs, these added structures not only help in securing satisfactory register of the two films, but serve also as a reference marking for the location of any details shown stereoscopically within the specimen.

The stereoscopic method is not often utilized in industrial radiography, but occasionally it may be of considerable value in localizing defects, or in visualizing the spatial arrangement of hidden structures.

Double Exposure (Parallax) Method

Figure 50 gives the details of this method. Lead markers (M_1) and (M_2) are fastened to the front and back, respectively, of the specimen. Two exposures are made, the tube being moved a known distance (a) from (F_1) to (F_2) between them. The position of the images of the markers (M_2) will change very little, perhaps imperceptibly, as a result of this tube shift, while the shadows of the flaw and marker (M_1) will change position by a larger amount.

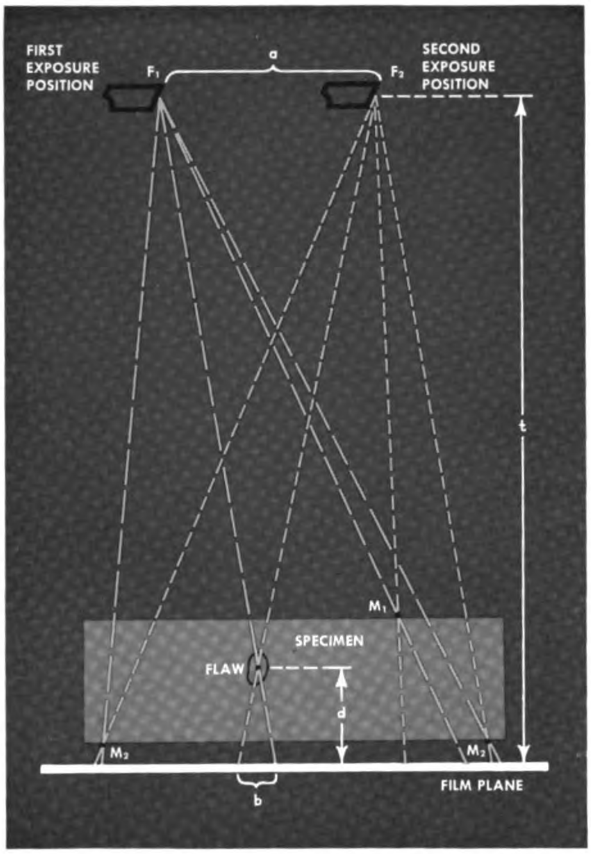

Fig. 50—Double exposure (parallax) technic for localizing defects.

If the flaw is sufficiently prominent, both exposures may be made on the same film. (One exposure "fogs" the other, thus interfering somewhat with the visibility of detail.) The distance of the flaw above the film plane is given by the equation

$$d = \frac{bt}{a + b}$$

where d = distance of the flaw above the film plane,
a = tube shift,
b = change in position of flaw image,
t = focus-film distance.

If the flaw is not sufficiently prominent to be observed easily when both exposures are made on the same film, two separate radiographs will be necessary. The shadows of the markers (M_2) are superimposed and the shift of the flaw image is measured. The equation given in the preceding paragraph is then applied to determine the distance of the flaw from the film.

In many cases, it is sufficient to know to which of the two surfaces of the part the flaw is nearest. In this case, the shifts of the images of the flaw and marker (M_1) are measured. If the shift of the flaw image is less than one-half the shift of marker (M_1), the flaw is nearer the film plane; if greater than one-half, it is nearer the plane of marker (M_1).

X-RAY DIFFRACTION

This application of x-rays has nothing in common with the shadow picture method ordinarily referred to as radiography. It is of considerable value, however, in the industrial laboratory, for by its use compounds may be identified, crystalline structures determined, and the effect on metals of cold work and annealing studied.

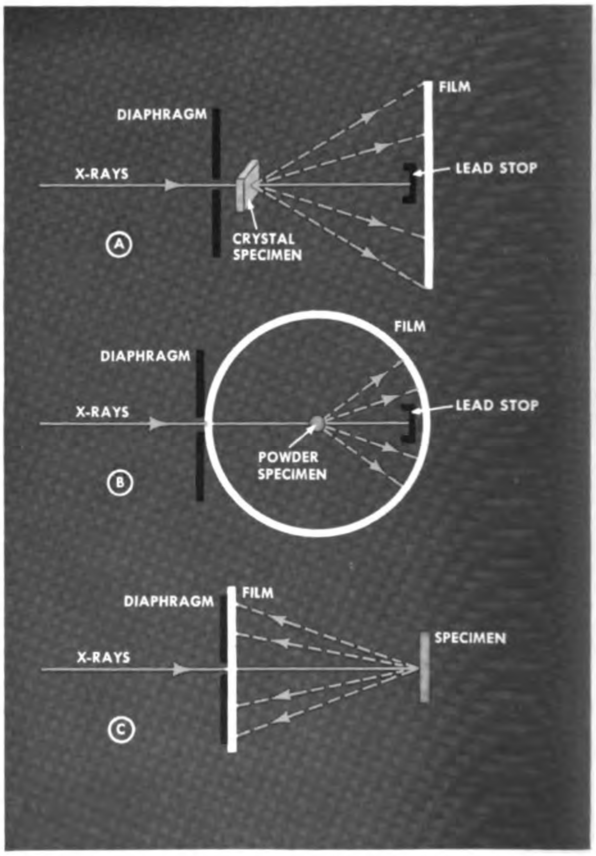

Fig. 51—Schematic diagrams of x-ray diffraction methods. (A) The Laue method uses heterogeneous radiation and a stationary crystal. In the Bragg method the crystal is rotated or oscillated and monochromatic radiation is used. (B) Debye-Scherrer-Hull (powder) method. (C) Back reflection method.

A crystal is made up of a definite geometric arrangement of atoms, and the regular planes thus established have the property of diffracting x-rays. In this process of diffraction, the x-rays are deflected in different directions and form a pattern on film, the character of this pattern being determined by the arrangement of atoms and tiny crystals in the specimen. If a change is brought about in the crystalline state of a material, by heat treatment, for example, the change will be registered in the pattern. X-ray diffraction is useful in pure research as well as in manufacturing process controls.

In the Laue method, a narrow beam of x-rays (Figure 51A) from the continuous spectrum passes through a single crystal of the material under investigation. The primary beam should be stopped at the film with a small piece of lead to prevent scattered x-rays from fogging the film. Some of the x-rays are diffracted, but only in particular directions, and the places where these rays impinge show as more or less dense spots on the developed film. The position of the spots is determined by Bragg's Law, viz., $n\lambda = 2d \sin \theta$ where n is the order of the spectrum, λ the wave length of the x-rays, d the distance between the atomic planes involved, and θ the angle between the diffracted x-ray and the atomic plane. Since a crystal is a regular pattern of atoms in space, there are many planes at different angles just as there are many different rows of trees with different spacings in an orchard, depending upon the angle at which the orchard is viewed. If the crystal of Figure 51A is properly oriented and suitably rotated or oscillated (Bragg's method), and the x-rays used are monochromatic, the data obtained are particularly useful for the determinations of the internal structures of crystals.

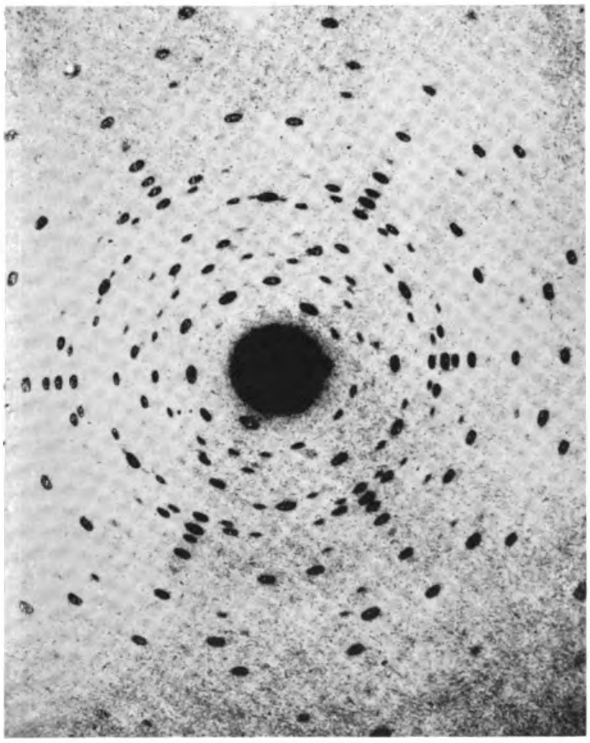

Fig. 52—X-ray diffraction pattern of "beta alumina" ($Na_2O \cdot 11\ Al_2O_3$) made by Laue method (Fig. 51A).

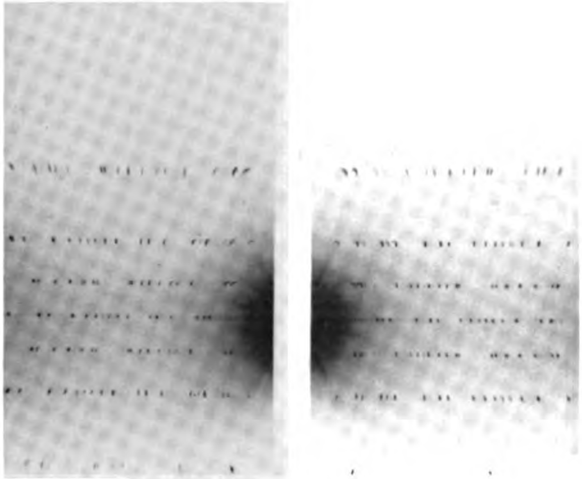

Fig. 53—Diffraction pattern of silver oxalate ($Ag_2C_2O_4$) made by the rotating crystal method (Fig. 51A).

Besides certain technical limitations of the Laue method, the necessity for always having a single crystal available is a handicap. The Debye-Scherrer-Hull method (Figure 51B) commonly utilizes a small amount of the sample in powdered form. It is mounted in a fine glass capillary, or may be stuck to a fiber or flat ribbon of material transparent to the x-rays. The resulting random distribution of tiny crystals permits the satisfying of Bragg's Law for many different lattice planes of the crystal. In this system, monochromatic x-rays are used. Determinations of crystal lattice constants may be made by the Debye-Scherrer-Hull method.

Some indication of the size of the crystals of the powder may be derived from the character of the

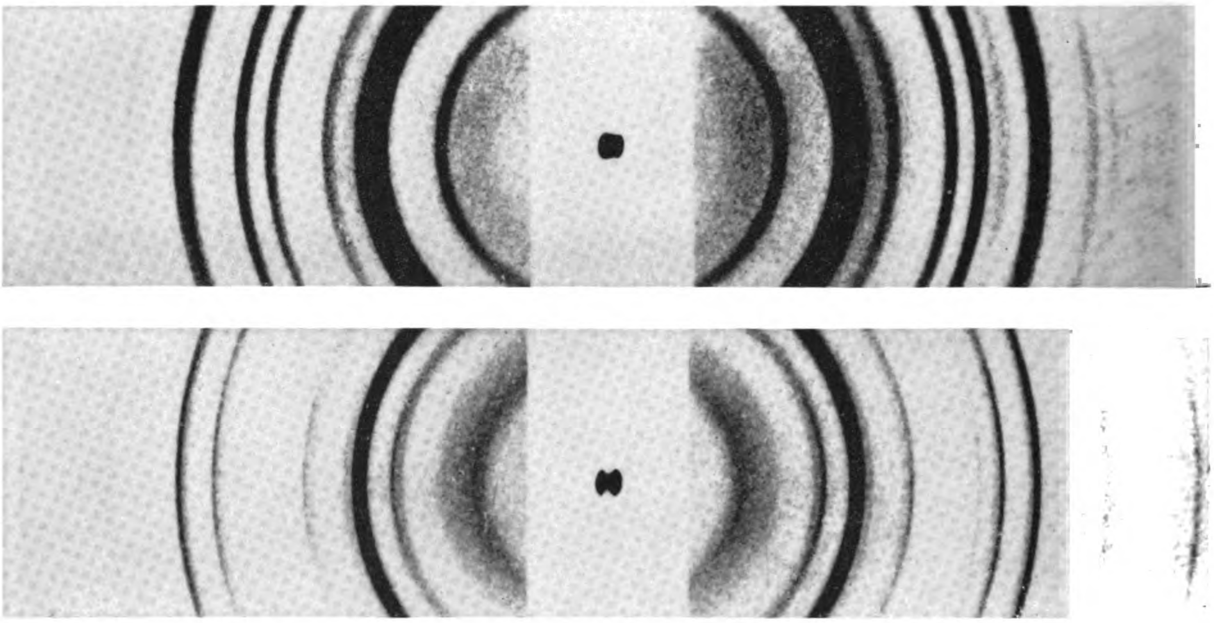

Fig. 54—Powder diffraction patterns by the Debye-Scherrer-Hull method (Fig. 51B).
Top: Ferric oxide Fe_2O_3 Bottom: Ferroso-ferric oxide Fe_3O_4

diffraction lines. The method also applies to the study of metallurgical samples in the form of foil since these are, in general, polycrystalline. If the specimen is sufficiently transparent to the x-rays, the arrangement in Figure 51A may be used but, if it is too thick, the rays diffracted backward would be used, as in Figure 51C. Information is thus derived as to mechanical strains and preferred orientations in the specimen, and as to the relation between these indications and the nature and amount of heat treatment or of mechanical working.

Recently a practical method has been devised for obtaining photographic representations of the structures of crystalline materials directly from the x-ray diffraction data. The procedure is a modification and extension of a method originally proposed by Sir W. Lawrence Bragg. The method permits one to obtain in less than an hour pictures of structures for which suitable x-ray diffraction data exist.

The first step in the process is to obtain a suitable x-ray diffraction photograph from a crystal of the substance being studied. By well-known methods, the diffraction spots are assigned indices, denoting the orientations of the reflecting planes of atoms relative to the unit cell. The intensities of these spots are then measured and certain corrections are applied to arrive at "structure factors" that are independent of the shape of the crystal and the geometry of the x-ray setup.

The diffraction photograph does not look at all like the structure from which it was produced. However, a second photographic step, using the list of indices and structure factors obtained from the first, yields a picture of the crystal structure as viewed in a given direction.

In this step, successive exposures on a single sheet of photographic film or paper of suitable characteristics are made through special masks—films having on them patterns of properly spaced and oriented bands such as those shown in Figure 55A. The masks used are determined by the indices of the x-ray diffraction spots and the signs of the structure factors. The relative lengths of exposure are determined by the magnitudes of the structure factors. Development and fixation of the film or paper after the multiple exposures yield the desired photograph.

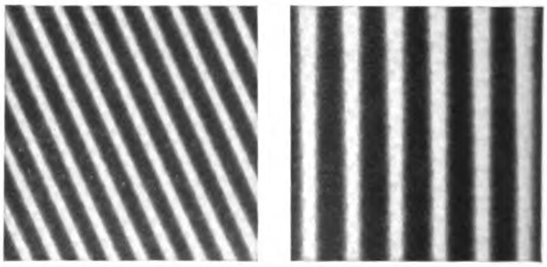

Fig. 55A—Examples of masks for making pictures of molecules.

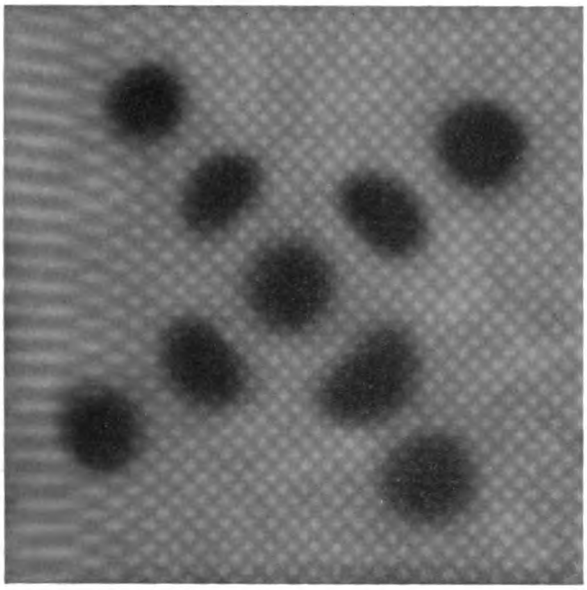

Fig. 55B—Picture of molecule of Pentaerythritol $C(CH_2OH)_4$

Figure 55B is an example of the sort of picture obtained. It shows a molecule of pentaerythritol, $C(CH_2OH)_4$. (X-ray data published by Llewellyn, Cox and Goodwin were used.) In this picture the carbon atoms are quite plainly indicated, but the hydrogen atoms not at all (since their diffracting power for x-rays is negligible). The arrangement of atoms in the molecule is precisely that previously deduced by organic chemists.

Films for X-ray Diffraction

Intensifying screens have rarely been used in diffraction exposures because the images are more diffuse when so produced. Furthermore, intensifying screens usually do not have as great an effect in shortening exposures in diffraction work as in radiography.

Because of its high contrast and high speed to direct x-rays, *Eastman No-Screen X-ray Film* is well suited as a recording medium in diffraction studies. Where it is desired to record a wide range of x-ray intensities within rather narrow density limits, *Kodak Industrial X-ray Film, Type F*, because of its lower contrast, is suitable. *Type A Film* may be used where a film of high definition is needed. The relative speeds and contrasts given in Column 1 of the tabulation, page 57, are approximately correct for x-ray diffraction work.

The parallax associated with an image on double-coated x-ray film may be objectionable in certain applications of x-ray diffraction. The emulsion may be removed from one side of a processed x-ray film by the following procedure. The film is processed in the normal manner although after washing it need not be dried unless desired, since the method is applicable to both wet and dry films. The film is then fastened to a sheet of glass with waterproof tape, and the emulsion surface to be removed is rubbed with a cotton swab saturated with one-half normal potassium hydroxide (28 grams of potassium hydroxide per litre). Care must be exercised to prevent this solution from coming in contact with the bare skin, clothing, or the emulsion surface which is to be preserved. After the film has been rubbed with the potassium hydroxide saturated swab for about one minute, the emulsion is usually soft enough to be scraped off with some smooth, dull implement which will not scratch the film base, e.g., a plastic paper knife. After the emulsion has been removed, the film is taken off the glass plate, rinsed a few seconds in running water, fixed for about 5 minutes and then washed and dried in the normal manner.

X-ray Diffraction References

American Society for Testing Materials, *X-ray Diffraction Data Cards.* Philadelphia, 1943.

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BUERGER, M. J., *X-ray Crystallography*, John Wiley and Sons, New York, 1942.

CLARK, G. L., *Applied X-rays*, McGraw-Hill, New York, 1940.

DAVEY, W. P., *A Study of Crystal Structure and Its Application*, McGraw-Hill, New York, 1934.

HIRST, H., *X-rays in Research and Industry*, Chemical Publishing Co., New York, 1943.

WYCKOFF, R. W. G., *The Structure of Crystals*, 2nd Edition, Chemical Catalog Co., New York, 1931.

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ZACHARIASEN, W. H., *Theory of X-ray Diffraction in Crystals*, J. Wiley & Sons, New York, 1944.

For references to recent developments in the field of x-ray diffraction, application may be made to the Secretary of the American Society for X-ray and Electron Diffraction, care of the American Institute of Physics, 57 East 55th Street, New York 22, N. Y.

Kodak
INDUSTRIAL X-RAY FILM
TYPE A
Kodak
INDUSTRIAL X-RAY
TYPE A
Kodak
INDUSTRIAL X-RAY
TYPE A
Kodak
INDUSTRIAL X-RAY FILM
TYPE A
Kodak
INDUSTRIAL X-RAY FILM
TYPE A
INDUSTRIAL X-RAY
TYPE A
TYPE M
INDUSTRIAL X-RAY
TYPE M
TYPE K
INDUSTRIAL X-RAY
TYPE K
TYPE F
INDUSTRIAL X-RAY
TYPE F
NO-SCREEN X-RAY
72 SHEETS
14 x 17 in.

KODAK INDUSTRIAL X-RAY FILMS

MODERN x-ray films for general radiography are composed of an emulsion—gelatin containing a silver compound—and a transparent, blue-tinted, cellulose acetate base. The emulsion is coated on both sides of the base in layers about 0.001-inch thick, to provide maximum speed and contrast in the film, and to allow developing, fixing, and drying in the shortest possible time.

The emulsion is very sensitive and, when x-rays, gamma rays, or light strike it, a change takes place in its physical structure. This change is of such a nature that it cannot be detected by ordinary physical methods. However, when the exposed film is treated with a chemical solution (called a *developer*) a reaction takes place, causing the formation of tiny granules of black, metallic silver. It is this silver, suspended in the gelatin on both sides of the base, which constitutes the image.

While an image may be formed by light and other forms of radiation, as well as by gamma rays or x-rays, the properties of the latter two are of a distinct character, and, for this reason, the sensitive emulsion must be different from those used in other types of photography. In fact, the wide range of conditions encountered in industrial radiography, and the variety of materials given radiographic examinations have led the Eastman Kodak Company to produce four specific types of film to meet these diverse requirements. These, together with two types of film designed primarily for medical use, and for which there are some industrial applications, are listed in the table on pages 56 and 57, and their principal characteristics are outlined. A more detailed discussion of the properties and uses of these films is given on the following pages.

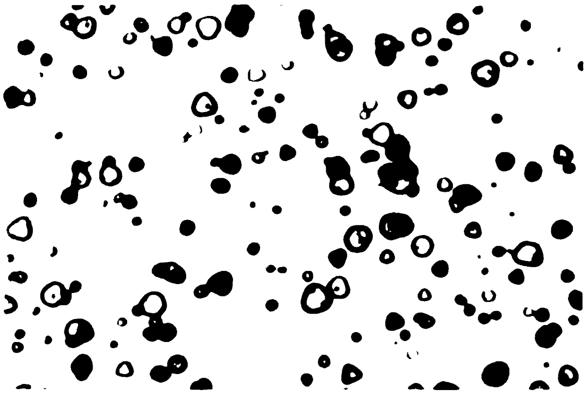


Fig. 56—The silver bromide grains of an x-ray film emulsion (2,500 diameters). These grains have been dispersed to show their shape and relative sizes more clearly. In an actual coating the crystals are much more closely packed.

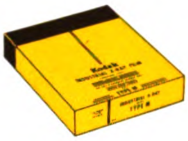
As pointed out at the beginning of this book, industrial radiography now has many widely diverse applications. In each application, there are many considerations in obtaining the best radiographic results. These include, for example: (1) the composition, shape, and size of the part being examined —and, in some cases, its weight and location as well; (2) the type of radiation used—whether x-rays from an x-ray machine, or gamma rays from radium salts; (3) the kilovoltages available with the x-ray equipment, or the intensity of the gamma radiation; (4) the kind of information sought—whether it is simply an over-all inspection, or the critical examination of some especially important portion, characteristic, or feature; and (5) the resulting relative emphases on definition, contrast, density, and the time required for proper exposure. All of these factors are important in the determination of the most effective combination of radiographic technic and film.

Here are descriptions of the six x-ray films produced by Kodak, together with a table of their relative speeds, contrasts, uses, and recommended development, and a detailed analysis of their applications in industrial procedures. Their characteristic curves are reproduced in Appendix 1, pages 91-97.

KODAK FILMS FOR

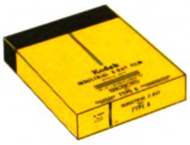
FILM CHARACTERISTICS

The choice of a film for a particular job depends upon the relative emphasis placed upon definition, contrast, and exposure time, and the available kilovoltages or intensity of gamma radiation.



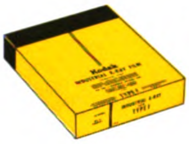
KODAK INDUSTRIAL
X-RAY FILM
TYPE M
(CODE NO. 5159)

EXTRA fine grain and high contrast. "Made to order" for critical inspecti
higher voltages, and the radiography of light metals such as aluminum, magnesi
and their alloys. Gives highest obtainable quality at 1000 to 2500 kilovolts. For
direct or with lead-foil screens.



KODAK INDUSTRIAL
X-RAY FILM
TYPE A
(CODE NO. 5160)

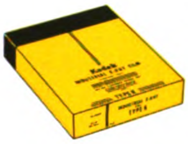
FINE grain and high contrast. Designed for the radiography of light metal
lower voltages and for 1000 to 2500 kilovolt radiography of heavier steel pa
Its grain is not quite as fine as that of Type M, but its higher speed makes it m
widely usable. For use direct or with lead-foil screens.



KODAK INDUSTRIAL
X-RAY FILM
TYPE F
(CODE NO. 5134)

HIGHEST available speed and high contrast when used with calcium tungst
screens. Useful for examination of steel, brass, etc., with machines of limi
kilovoltage.

Lower contrast when used direct or with lead-foil screens. Records large ra
of thicknesses in relatively small density range.



KODAK INDUSTRIAL
X-RAY FILM
TYPE K
(CODE NO. 5135)

HIGHEST available speed for gamma-ray work when used direct or with lead
screens.

(In work with calcium tungstate screens, Type K has about 1/10 the speed
Type F, but has higher contrast and greater density range.)

EASTMAN
NO-SCREEN
X-RAY FILM
(CODE NO. 5133)

USEFUL where higher contrast than that of Type K is needed. Where somew
lower speed can be tolerated, its high contrast makes it especially suitable
gamma-ray exposures. For use direct or with lead-foil screens.

EASTMAN
BLUE BRAND
X-RAY FILM
(CODE NO. 5121)

IN WORK with calcium tungstate screens, Blue Brand is slightly slower th
Type F under industrial conditions.

When used direct or with lead-foil screens, Blue Brand is similar to Type F u
under the same conditions.

RIAL RADIOGRAPHY

RELATIVE SPEED AND CONTRAST

: relative speeds and contrasts given below apply only to the use of the film in direct osures or with lead-foil screens, as indicated, and when given normal development. 'he Type F and Blue Brand films are primarily intended for exposure with calcium gstate intensifying screens; under such conditions, their speed and contrast are much ıer than indicated below.

'he values listed in column one below are approximately correct for x-ray diffrac- ı work.

DEVELOPMENT

Kodak Liquid X-ray Developer and Replenisher or *Kodak Rapid X-ray Developer*

	Aluminum and other light alloys No screens	Thin steel and brass Lead-foil screens	With million-volt x-rays Lead-foil screens	With gamma rays Lead-foil screens	Normal Development at 68°F. (20°C.) Minutes	For max. speed and contrast at 68°F. (20°C.) Minutes
TIVE ED	30	40	30	30	5	8
RAST	HIGH	HIGH	HIGH	HIGH		
TIVE ED	100	100	100	100	5	8
RAST	HIGH	HIGH	HIGH	HIGH		
TIVE ED	200	200	200	360	5	5
RAST	MEDIUM	MEDIUM	MEDIUM	MEDIUM		
TIVE ED	530	400	425	500	5	8
RAST	MEDIUM	MEDIUM	MEDIUM	MEDIUM		
TIVE ED	600	400	250	300	5	8
RAST	HIGH	HIGH	HIGH	HIGH		
TIVE ED	200	200	200	360	5	5
RAST	MEDIUM	MEDIUM	MEDIUM	MEDIUM		

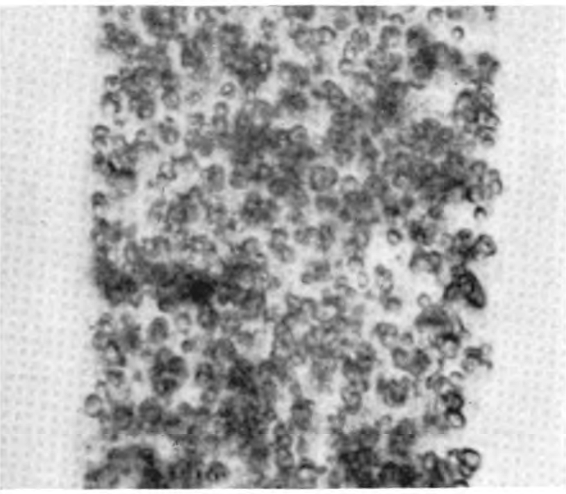


Fig. 57—Cross section of the unprocessed emulsion on one side of an x-ray film (2,000 diameters). Note large number of grains as compared to the developed grains of Figure 58.

Kodak Industrial X-ray Film, Type M, is an extra-fine-grain, high-contrast film designed to meet the widening use of higher kilovoltages, the growing importance of radiography in the study of light alloys, and the increasing emphasis on critical examination in industry, generally. In direct exposures, or with lead foil screens, the extra-fine grain and high contrast of *Type M Film* provide the utmost in radiographic sensitivity in any use in which the necessary exposure can be given. Its speed is adequate for the radiography of light alloys at average kilovoltages, as such materials are readily penetrable by x-rays and do not require heavy exposures. Because of the high output of penetrating radiation of x-ray generators operating at one million volts or more, *Type M Film* is suitable for most work with those machines, especially relatively thin steel parts.

Kodak Industrial X-ray Film, Type A, is a fine-grain, high-contrast film for use direct, or with lead foil screens. It is similar in its characteristics to *Type M Film.* Its grain is not quite as fine, but its speed, approximately three times that of *Type M,* makes it more widely usable. It is recommended for the examination of light alloys at lower voltages and for radiography of heavier steel parts at one million volts and higher. With gamma rays as well as x-rays, *Type A Film* gives superior definition and is especially suitable for all work in which higher film speed is not required.

Kodak Industrial X-ray Film, Type F, is especially designed for use with calcium tungstate intensifying screens, with which it provides the highest available speed and high contrast. It may also be used direct, or with lead foil screens, for both x-ray and gamma-ray exposures, under which conditions it has medium contrast. In all work where the intensification of calcium tungstate screens is necessary to reduce exposures to reasonable times—such as in the radiographic examination of thick steel parts—*Type F Film* is first choice.

Kodak Industrial X-ray Film, Type K, is a medium contrast film. When definition is important and calcium tungstate intensifying screens are not required, *Type K* is recommended. The selection of *Type M, A, K,* or *No-Screen* depends upon the emphasis on definition and the film speed needed for the particular work. *Type K Film's* high speed makes it especially advantageous when gamma radiation is used.

Eastman No-Screen X-ray Film is a high contrast film designed for use direct or with lead foil screens. Its contrast is between that of *Types A* and *K,* and it is used principally in the radiography of iron and steel direct, or with lead foil screens. Its high contrast makes it useful in gamma-ray exposures.

Eastman Blue Brand X-ray Film is Kodak's other film designed for use with calcium tungstate intensifying screens. In general, it is similar to *Type F Film.* With direct x-rays, and when lead foil screens are used, its speed is approximately the same but, with calcium tungstate screens, slightly more exposure is required.

The relative speeds of the various radiographic films depend somewhat on radiation quality, as is shown in the table on pages 56 and 57.

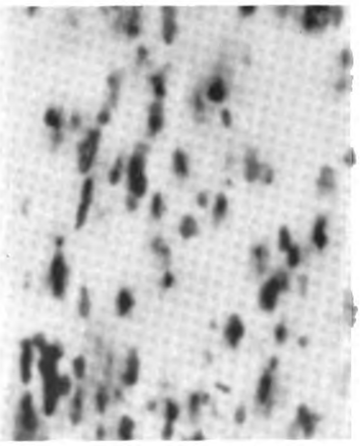


Fig. 58—Cross section (2,000 diameters) showing the distribution of developed silver grains in an x-ray emulsion exposed to give a moderate density.

KODAK FILMS SUGGESTED FOR VARIOUS APPLICATIONS

MATERIAL Thickness in Inches	KILOVOLTAGE RANGE Under 50 KvP	50—80	80—120	120—150	150—250	250—400	1000
Magnesium							
0–¼	M	M	M				
¼–½	A	M	M	M			
½–1	A; NS or K	A	M	M			
1–2		A	M	M	M		
2–4		NS or K	A	A or M	M		
over 4			NS or K	A	M		
Aluminum							
0–¼	A	M	M				
¼–½	A; NS or K	A	M	M			
½–1		A	M	M			
1–2		NS or K	A	M	M		
2–4		F* or BB*	NS or K	A	M		
over 4			NS or K	NS or K	A		
Steel							
0–¼		NS or K	NS or K	A	M		M
¼–½		F* or BB*	NS or K	A	A	M	M
½–1			F* or BB*	NS or K	A; NS or K	A	M
1–2				F* or BB*	NS; F* or BB*	A	M
2–4					F* or BB*	NS; F* or BB*	A or M
over 4						F* or BB*	A
Bronze							
0–¼		NS or K; F* or BB*	NS or K	A	M	M	M
¼–½			NS or K	A	A	M	M
½–1			F* or BB*	NS or K; F* or BB*	NS or K	A	M
1–2				F* or BB*	F* or BB*	NS or K	M
2–4						F* or BB*	A
over 4							K or NS

*Where Type F and Blue Brand are referred to in the above tabulation, they are to be exposed with calcium tungstate intensifying screens.

Improving quality ⟶

Type F with calcium tungstate screens   No-Screen or Type K   Type A   Type M

⟵ Increasing speed

SELECTION OF FILMS FOR INDUSTRIAL RADIOGRAPHY

The selection of a film for the radiography of any particular part depends upon the thickness and material of the specimen and upon the voltage range of the available x-ray machine. In addition, the choice is affected by the relative importance of high radiographic quality or short exposure time.

The tabulation on page 59 lists the films which usually prove satisfactory for certain classes of work. An attempt has been made to balance the two opposing factors of high quality and short exposure time. It is not possible, however, to present definite rules on the selection of a film. If high quality is the deciding factor, a slower, and hence finer grained, film should be substituted for the one recommended —e.g., for the radiography of steel up to ¼-inch thick at 120-150 KvP, substitute *Type M* for *Type A*. If short exposure times are essential, a faster film should be used in place of the one given on page 59. For example, 1-inch steel may be radiographed at 200 KvP, using *Type F* with calcium tungstate screens instead of *No-Screen Film* or *Type K Film.*

The above diagram will help in making these substitutions where necessary.

RADIOGRAPHY WITH CALCIUM TUNGSTATE INTENSIFYING SCREENS

In radiography requiring the highest possible photographic speed, calcium tungstate intensifying screens must be used (see page 23). Their fluorescent light has a much greater photographic action than that of the x-rays alone. *Kodak Industrial X-ray Film, Type F,* when exposed to the light emitted by intensifying screens, has maximum speed, combined with high contrast.

To secure adequate exposure within a reasonable time, *Type F Film,* with double intensifying screens, should be employed in the radiography of steel in thicknesses about 1½ inches at 200 KvP, and above 3 inches at 400 KvP. *Eastman Blue Brand X-ray Film,* intended for medical radiography, is similar in quality to *Type F Film,* but is slower when used with calcium tungstate screens, requiring slightly greater exposure under average industrial conditions.

Type K Film, when exposed with calcium tungstate intensifying screens, has a speed about 1/10 that of *Type F* under the same conditions. However, it exhibits a higher contrast and higher maximum density than does *Type F,* features which may be useful in special instances.

GAMMA-RADIOGRAPHY

Kodak Industrial X-ray Film, Type K, offers the highest available speed for gamma-ray exposures, and is recommended for all work where exposure time must be kept to a minimum.

Kodak Industrial X-ray Film, Type F, is slower, but finer grained than *Type K,* and, from most standpoints, is the most satisfactory choice for gamma-radiography.

Eastman No-Screen X-ray Film is still slower, but often is preferred for use with gamma rays because of its high contrast.

Kodak Industrial X-ray Films, Types M and *A,* by reason of their fine grain and high contrast, provide the finest available radiographic quality with gamma rays in any situation where the necessary exposure can be given. *Types M* and *A* are particularly useful when thin materials must be radiographed with gamma rays.

In gamma-ray radiography the processing recommendations "for maximum speed and contrast" should be followed (see chart, pages 56 and 57).

HANDLING OF FILM

X-ray films should always be handled carefully to avoid physical strains, such as pressure, creasing, buckling, friction, etc. The normal pressure applied in a cassette to provide good contact is not enough to damage the film, but, whenever films are loaded

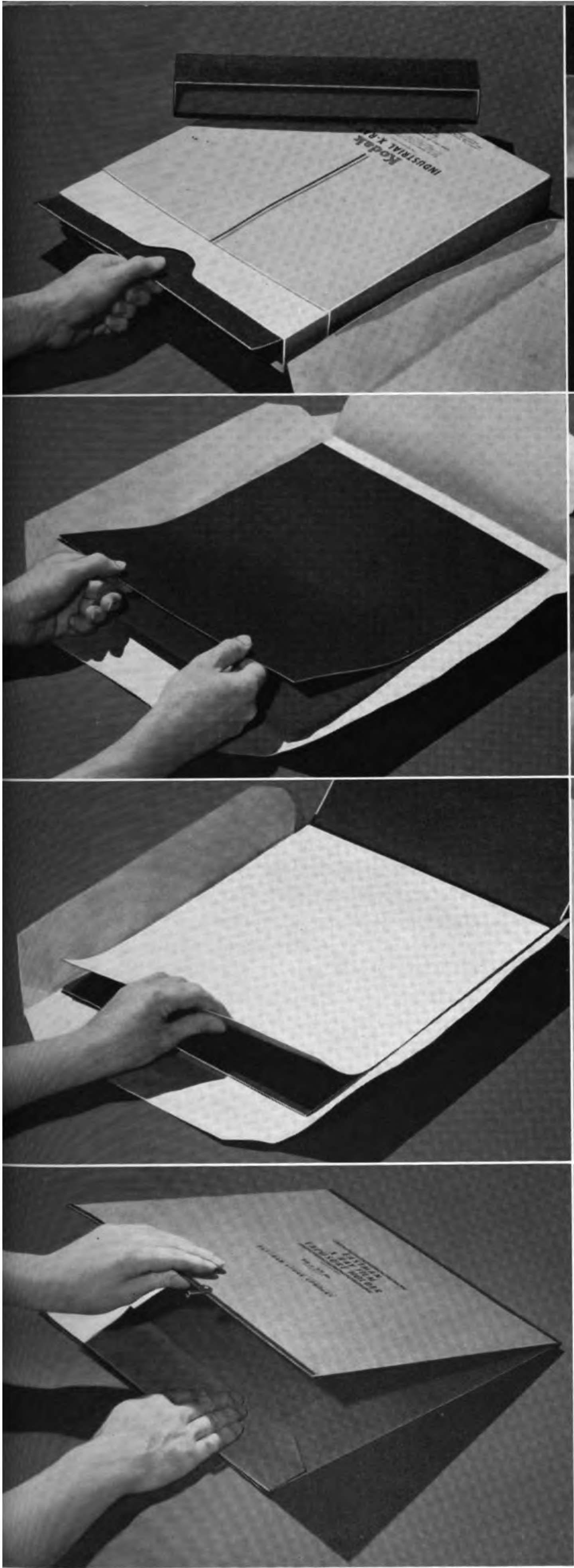


Fig. 59—Method of placing a film in an *Eastman X-ray Exposure Holder.*

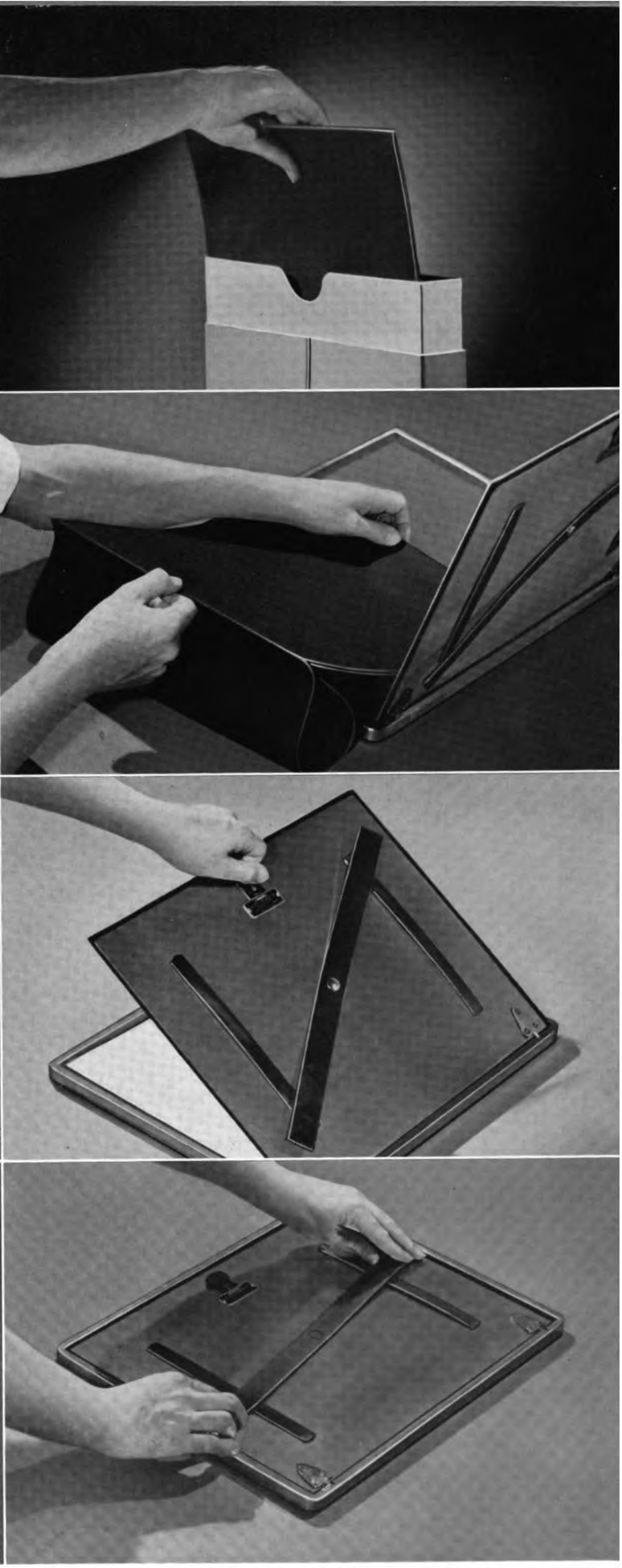


Fig. 60—Method of placing film in a cassette.

in semiflexible holders and external clamping devices are used, care should be taken to see that this pressure is uniform. If the film holder bears against a few high spots, such as occur on a welded seam, the pressure may be great enough to produce desensitized areas.

If large films are always grasped by the edges and allowed to hang freely, as shown in Figures 59 and 60, marks resulting from contact with fingers which are moist or contaminated with processing chemicals, as well as crimp marks, will be avoided. A handy supply of clean towels is an incentive to dry the hands often and well.

Another important precaution to remember is to avoid drawing film rapidly from cartons, exposure holders, or cassettes, or handling it in any manner that would cause friction. Such care will help materially to eliminate the occurrence of objectionable circular or tree-like black markings in the radiograph, the results of static electrical discharges.

In loading intensifying screen cassettes, care must be taken to remove the paper which is placed around the individual films in packing. This also applies to use with lead foil screens. When using exposure holders in direct-exposure technic, however, the paper should be left on the film for the added protection that it provides. At high voltages, direct-exposure technics are open to the objection pointed out on page 20, that electrons emitted by the lead backing of the cassette or exposure holder may reach the film through the intervening paper or felt, and record an image of this material on the film. This effect is avoided by the use of lead foil or calcium tungstate intensifying screens. In the radiography of light metals, however, direct exposure technics are the rule; and in this case the paper folder in which each sheet of film is packed should be left on the film when loading it in the exposure holder.

Eastman X-ray Film Exposure Holders are made especially for this procedure. They consist of two pieces of cardboard hinged together and fastened with a pivoted clasp. A sheet of special paper which folds to form an envelope is provided for holding the film. In loading, the film is placed in the open holder; next, the large flap of the envelope is turned down so that it is flat on the film; the side flaps are then brought over, followed by the bottom flap. The final operation is to bring the cardboard covers together and fasten them securely with the clasp.

INCORPORATING IDENTIFICATION DATA IN RADIOGRAPHS

Because of their great opacity, lead numbers or letters affixed to the subject furnish a simple means of identifying radiographs and of determining the location of defects by using them as reference marks. They may be conveniently fastened to the object with adhesive tape, combining legibility with easy removal. A code may be devised to minimize the amount of lettering needed.

PROTECTION OF X-RAY FILM IN STORAGE

Film manufactured expressly for radiography naturally is particularly sensitive to the action of x-rays and radium. Therefore, x-ray film in storage should be properly protected against exposure to stray x-rays and gamma rays. With x-rays generated up to 200 kilovolts, it is feasible to use storage compartments lined with a sufficient thickness of lead to protect the film. At higher voltages, protection becomes increasingly difficult, and in addition to a suitable thickness of protective material, adequate distance between the source of radiation and the film must be allowed.

The degree of protection necessary depends upon various factors, such as the intensity and penetrating power of the radiation, as well as the total accumulation of exposure. At 100 kilovolts, a ⅛-inch thickness of lead should normally be adequate to protect film stored in a room adjacent to the x-ray room if the film is not in the line of the direct beam. At 200 kilovolts, the lead thickness should be increased to ¼ inch. With million-volt x-rays, *Kodak Industrial X-ray Film, Types M* and *A*, should be stored beyond the concrete or other protective wall at a distance from the x-ray tube at least five times that occupied by the personnel, and the storage period should not exceed two weeks for *Type A*, or five weeks for *Type M.* A supply of these films sufficient for only a half-day's work should be kept in the processing room. Faster films, such as *Kodak Industrial X-ray Film, Types F* and *K*, and *Blue Brand* and *No-Screen X-ray Films*, should be stored approximately at ten times the distance of the personnel from the million-volt x-ray tube, for a total period not exceeding two weeks.

When not in use, radium should be kept in a lead container. While it is being used for radiography, the only feasible protection for stored film is to keep it at a sufficient distance from the radium. The conditions for the safe storage of x-ray film in the vicinity of radium are given in the table below.

Because of the deleterious effect of heat and moisture, all film should be stored in a cool, dry place and ordered in such quantities that the supply on hand is renewed frequently.

Under no circumstances should film be left in a chemical storage room or in any location where there is leakage of illuminating gas or any other types of gases, or where there is a possibility of contact with formalin vapors, hydrogen sulfide, ammonia, or hydrogen peroxide.

Kodak x-ray films present no greater fire hazard in storage in the x-ray laboratory and filing room than an equal quantity of paper records. Thus, there is no necessity for expensive vaults, equipped with elaborate fire-protection appliances. The Underwriters' Laboratories, Inc., have accredited *Kodak Industrial X-ray Film* as follows: "Hazards of this slow-burning film when in use are judged to be small, and, in storage, somewhat less than would be presented by common newsprint paper in the same form and quantity."

The table below shows distances, varying amounts of radium, and thicknesses of protective lead surrounding the radium, which will produce a slight but harmless degree of fog on *Kodak Industrial X-ray Film, Type K,* when stored for a two weeks' period in the vicinity of radium. The lead protection and distance should be considered as minimum conditions tolerable. Other x-ray films may be stored under these same conditions for the following periods:

Kodak Industrial X-ray Film, Type M	30 weeks
Kodak Industrial X-ray Film, Type A	12 weeks
Kodak Industrial X-ray Film, Type F	3 weeks
Eastman Blue Brand X-ray Film	3 weeks
Eastman No-Screen X-ray Film	4 weeks

FILM STORAGE TABLE

Lead Surrounding Radium in Inches

Distance in Feet	**Amount of Radium in Milligrams**									
	25	**50**	**75**	**100**	**150**	**200**	**300**	**400**	**500**	**600**
25	2.5	3.0	3.0	3.5	3.5	4.0	4.0	4.5	4.5	4.5
50	1.5	2.0	2.0	2.5	2.5	3.0	3.0	3.5	3.5	3.5
100	0.5	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	2.5
200	0	0	0	0.5	0.5	1.0	1.0	1.5	1.5	1.5
400	0	0	0	0	0	0	0	0.5	0.5	0.5

FOR PHOTOGRAPHIC OR TECHNICAL PURPOSES ONLY
Kodak
RAPID X-RAY DEVELOPER
25-GALLON SIZE
EASTMAN KODAK COMPANY
KEEP DRY
FOR PHOTOGRAPHIC OR TECHNICAL PURPOSES ONLY
Kodak
RAPID X-RAY DEVELOPER
(A KODALK FORMULA • CONTAINS CAUSTIC SODA)
5-GALLON SIZE
EASTMAN KODAK COMPANY
Kodak
RAPID X-RAY DEVELOPER
(A KODALK FORMULA)
1-GALLON SIZE

FOR PHOTOGRAPHIC OR TECHNICAL PURPOSES ONLY
Kodak
RAPID X-RAY DEVELOPER
(A KODALK FORMULA • CONTAINS CAUSTIC SODA)
5-GALLON SIZE
EASTMAN KODAK COMPANY
FOR PHOTOGRAPHIC OR TECHNICAL PURPOSES ONLY
Kodak
RAPID X-RAY REPLENISHER
USE WITH KODAK RAPID X-RAY DEVELOPER
KODALK FORMULA • CONTAINS CAUSTIC SODA
5-GALLON SIZE
EASTMAN KODAK COMPANY
FOR PHOTOGRAPHIC PURPOSES ONLY
Kodak
LIQUID X-RAY DEVELOPER AND REPLENISHER
(A KODALK FORMULA)
5-GALLON SIZE
EASTMAN KODAK COMPANY
FOR PHOTOGRAPHIC PURPOSES ONLY
Kodak
LIQUID X-RAY FIXER AND REPLENISHER
5-GALLON SIZE
EASTMAN KODAK COMPANY
Kodak
AUXILIARY POWDER
Kodak
HARDENER
KODAK LIQUID X-RAY FIXER AND REPLENISHER
SOLUTION B
5-GALLON SIZE
EASTMAN KODAK COMPANY

PROCESSING

In the processing procedure, the invisible latent image produced in the film by exposure to x-rays or light is made visible and permanent. Processing is carried on under subdued lights which do not affect the sensitive emulsion. The film is first immersed in a developing solution which causes the areas exposed to light or x-rays to become dark, the amount of darkening for a given degree of development depending upon the degree of exposure. After developing, the film is rinsed, preferably in an acid bath, to stop development. The film is next put into a fixing bath which dissolves away the undarkened portions of the sensitive salt, and then is washed to remove the fixing chemicals and solubilized sensitive salts.

GENERAL CONSIDERATIONS

Tank Processing

The most common method of processing industrial radiographs is known as the tank processing system. In this system, the processing solutions and washing water are contained in tanks deep enough for the largest film used to be hung in them vertically. This method has several advantages in the processing of radiographs. The processing solutions have free access to both sides of the film, and both emulsion surfaces are uniformly processed to the same degree. The all-important factor of temperature can be controlled by regulating the water bath in which the processing tanks are immersed. The tank system is economical of space, and is timesaving.

When tank processing is provided, the routine is first to mount the exposed film on a hanger, such as the *Kodak X-ray Processing Hanger, No. 3*, immediately after it is taken from the cassette or film holder. (See Figures 61-63.) Then the film can be conveniently immersed in the developer solution, rinse bath, fixer solution, and wash water for the predetermined intervals, and it will be held securely and taut throughout the processing procedure.

At frequent intervals during development, at the end of each minute, for example, films must be agitated in the solution so as to promote renewal of developer at the surface of the films. Otherwise, the solution in contact with the emulsion becomes exhausted, affecting the rate and evenness of development.

Another precaution must be observed in this method, and that is to be certain that the level of the developer solution is kept constant by adding fresh solution or replenisher from a stock supply. This addition is necessary to replace solution absorbed by the dry films when they are first immersed, for one 14 x 17-inch film may retain as much as 1½ oz. of solution even if it is carefully drained when taken from the tank.

For convenience in emptying solution tanks that do not have an outlet, the Scott Water Pump* may be used. This device consists of a three-branched rubber hose, one branch for connecting to a water faucet and the others for placing in the solution tank and in the sink, respectively. When the faucet is turned on, the pump will drain the tank rapidly. It can also be used to clean tanks by rinsing with water entering through the outlet, and removing it through the draining bench.

Cleanliness

Owing to the sensitivity of x-ray film emulsions, cleanliness is a prime essential in processing procedure. It is imperative that the processing room, as well as the accessories and equipment, be kept scrupulously clean, and that they be used only for the purposes for which they are intended. Any solutions that are spilled should be wiped up at once; otherwise, upon evaporation, the chemicals may

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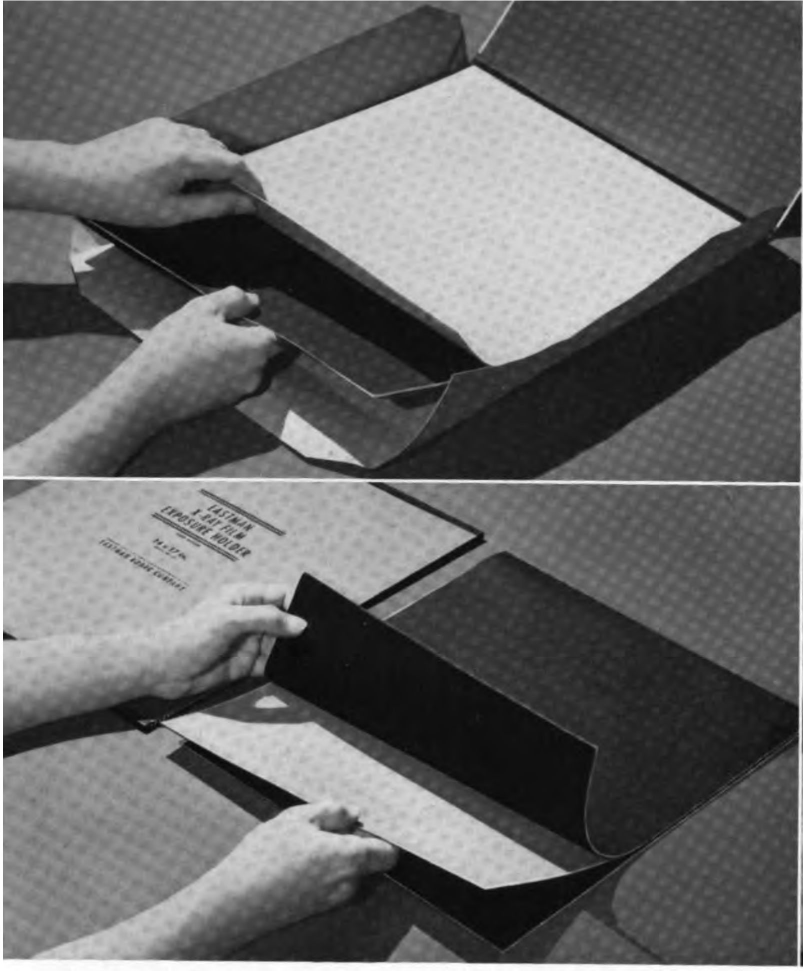
*Obtainable from the Scott Pump Company, Rochester, N. Y.



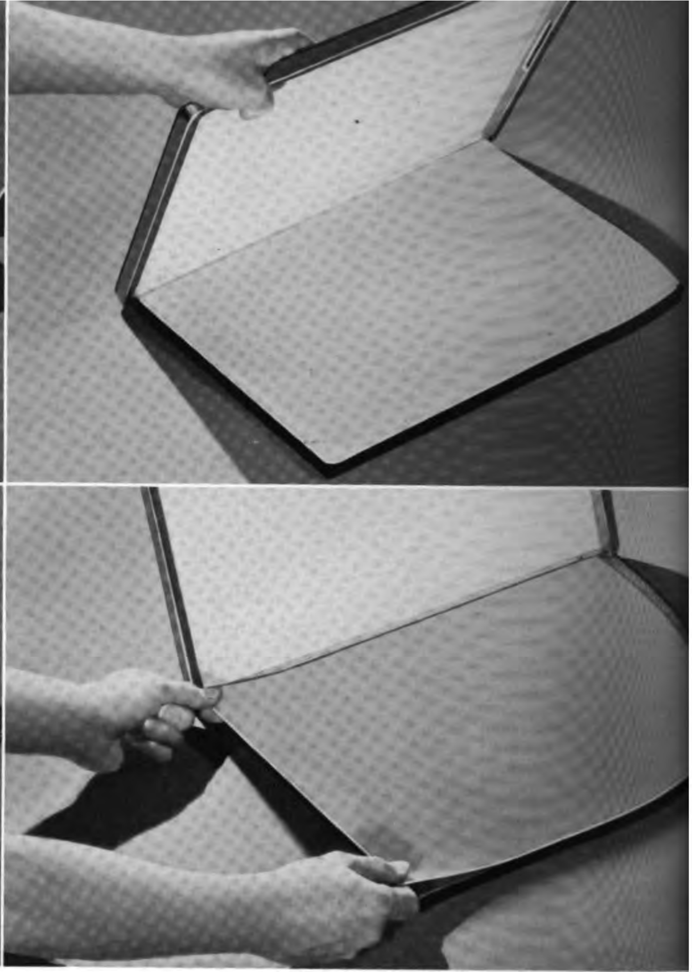
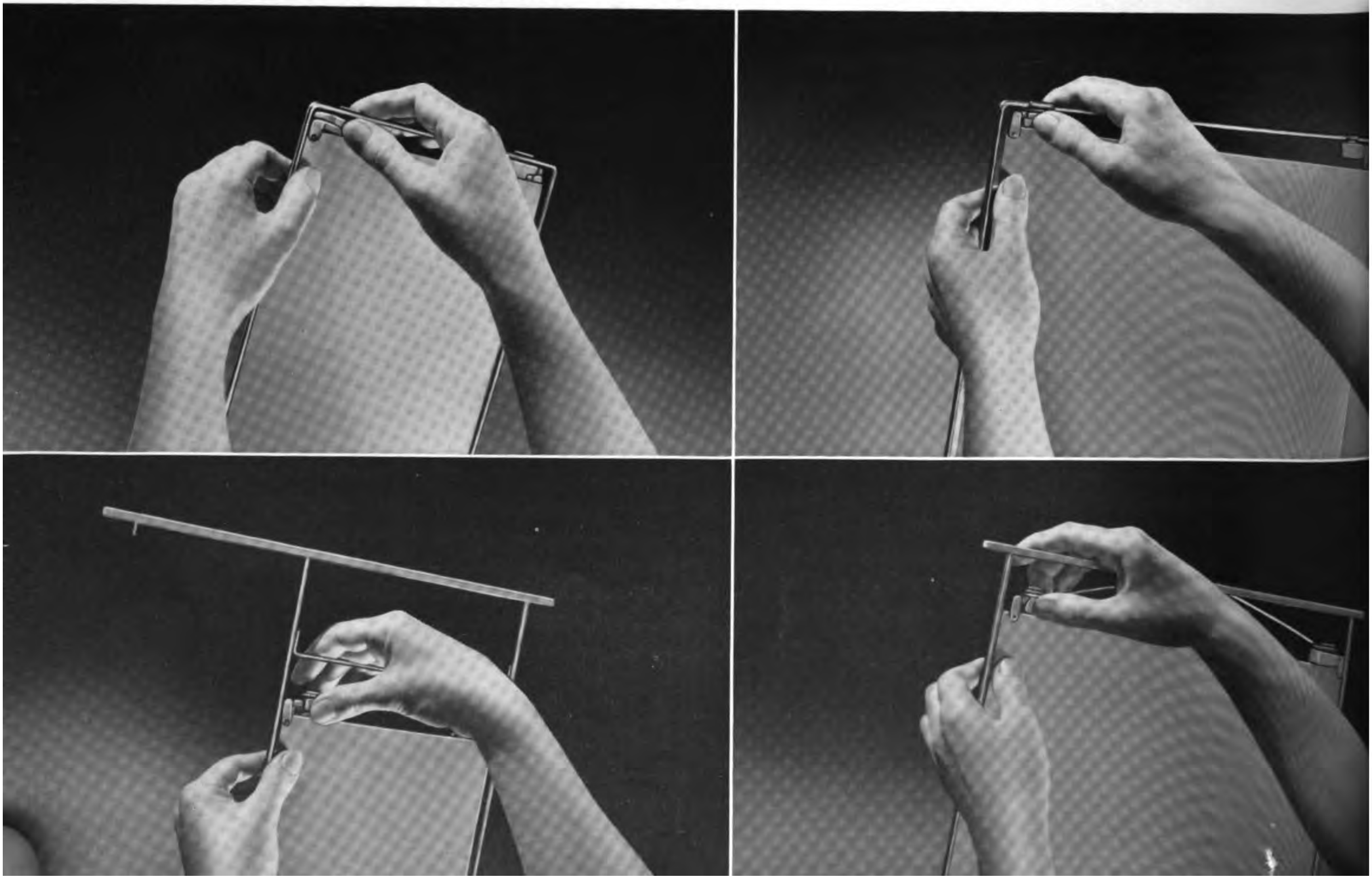


Fig. 61—Method of removing a film from an *Eastman X-ray Exposure Holder*

Fig. 62—Method of removing a film from a cassette.

Fig. 63—Method of fastening film on a developing hanger. Bottom clips are fastened first, followed by top clips.



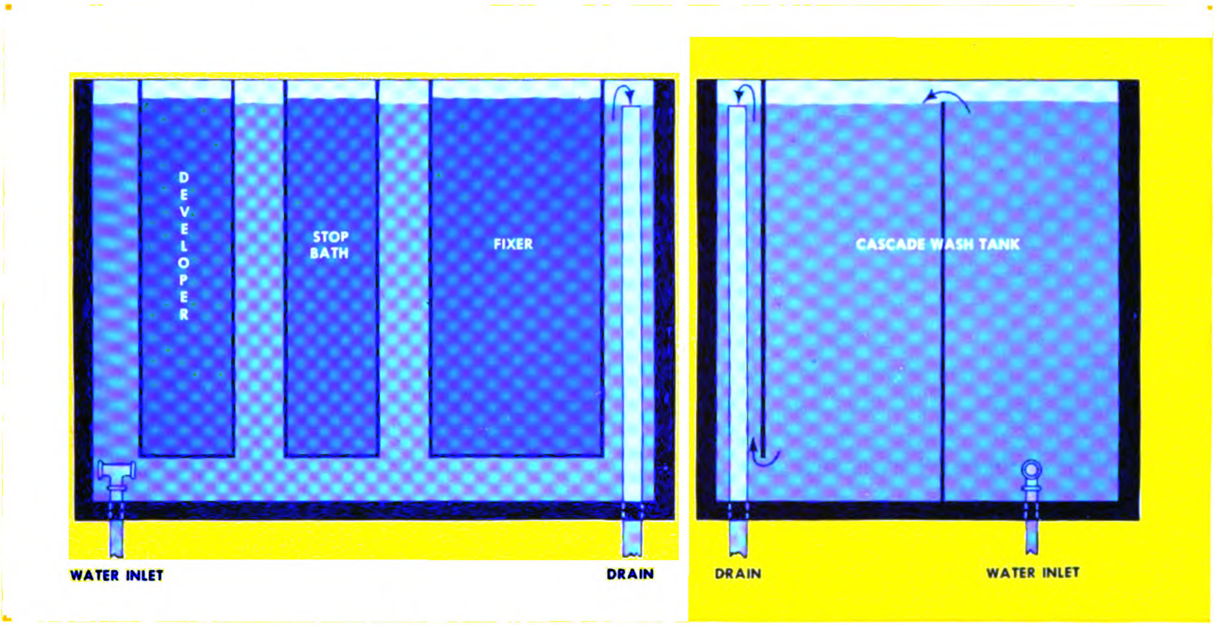


Fig. 64—Schematic diagram of a tank processing unit.

get into the air and later settle on film surfaces, causing spots. The thermometer and film hangers should be thoroughly washed in clean water immediately after being used, so that solutions will not dry on them and possibly cause contamination or streaked radiographs when used again. Processing tanks should be scrubbed thoroughly before putting fresh solutions in them. In warm weather especially, it is advisable to sterilize developer tanks occasionally, by allowing a solution of sodium hypochlorite (5% Clorox, Sunny Sol, etc.) to remain in the tank overnight and then rinsing thoroughly.

Mixing Processing Solutions

There are certain precautions that must be observed in mixing processing solutions. The vessels or pails should be made of enamelware, 18-8 molybdenum stainless steel, glass, hard rubber, or glazed earthenware, since metals such as aluminum, galvanized iron, tin, copper, and zinc will cause contamination and result in fog in the radiograph.

Wooden paddles about 36 inches long—one for developer and one for fixer solution—are practical for stirring. If they are washed thoroughly and hung up immediately after use, drying will take place rapidly and the danger of contamination when they are employed again will be virtually nil. A motor-driven stirrer with a stainless steel propeller is a convenient aid in mixing solutions.

DEVELOPMENT

Developing Solutions

Prepared developers which are made ready for use by dissolving in water or by dilution with water insure a carefully compounded formula and uniformity of results. The Kodalk formula recommended for industrial radiography is available in two forms: *Kodak Rapid X-ray Developer* (powders), and *Kodak Liquid X-ray Developer and Replenisher*. They are comparable in performance and effective life, but the liquid form offers greater convenience in preparation which may be extremely important in a busy laboratory.

Normal developing time for industrial x-ray films in these solutions is 5 minutes at 68°F. (20°C.) as shown in the table on pages 56 and 57. *Kodak Liquid X-ray Developer and Replenisher*, however, may also be used as a fast developer when mixed according to special directions on the package, and the normal developing time is reduced to 3 minutes at 68°F. In a laboratory where the processing capacity is overloaded, this saving speeds up the work so that finished radiographs can be delivered to the reading rooms promptly, keeping the inspectors in more current touch with the work in the shop. *Kodak Liquid X-ray Developer and Replenisher* may, in addition, be used as a replenisher (see pages 70 and 71) to maintain original development time, and extend the life of the solution.

Importance of Standardized Developing Procedure

When the exposed film is placed in the developer, the solution penetrates the emulsion and begins to reduce the exposed crystals to metallic silver. The longer the development is carried on, the more silver is formed and the blacker the image becomes.

The rate of development is affected by the temperature of the solution. As the temperature rises, the rate of development increases. Thus, when the developer temperature is low, the reaction is slow and the development time recommended for the normal temperature would give underdevelopment. When the temperature is high, the reaction is fast, and the same time would give overdevelopment. Within certain limits, these changes in the rate of development can be compensated for by increasing or decreasing the time of development.

In the time-temperature system of development, which should be used in all radiographic work, the developer is always kept within a certain small temperature range and the time of development is adjusted according to the temperature, in such a way that the degree of development remains the same. Development should not be changed to offset errors in exposure.

Standardized time-temperature procedure is important because the chemical reactions can properly take place only within a very limited time and temperature range. If it is not carefully observed, the effects of even the most accurate exposure technic will be nullified. No film is capable of withstanding the effect of errors resulting from guesswork in processing.

Another advantage of standardized time-temperature processing procedure is that a definite check on exposure time always may be made, thereby precluding a large percentage of errors that might otherwise occur in the production of radiographs.

For example, the image recorded in the emulsion of *Kodak Industrial X-ray Film*, by correct exposure, will usually be fully developed and present the normally desired contrast and density after the film has remained for 5 minutes with occasional agitation in fresh solution properly prepared from *Kodak Liquid X-ray Developer and Replenisher* or *Kodak Rapid X-ray Developer* (powders), at 68°F. (20°C.). When radiographs of higher contrast are desired, see the table on pages 56 and 57 for suggested increases in development time. In either instance, however, when the processing factors are correct and the radiographs are found to lack density, it can be assumed that underexposure has taken place; when the radiographic image is too dense, overexposure is indicated. The first condition can be corrected by increasing the exposure time and the second, by decreasing it; to be appreciable, any change should be an increase or a decrease of the original time factor by at least 40 per cent.

Control of Temperature

The temperature of the processing solutions has a decided influence on their activity, so careful control of this factor is very important. It should be an established rule that the temperature of the developer solution is to be checked immediately before films are immersed in it, so that they can be left in for the proper length of time.

The temperature of the developer solution should be 68°F. (20°C.). A temperature below 65°F. (18°C.) retards the action of the chemicals, and is likely to result in underdevelopment, whereas an excessively high temperature may not only destroy the photographic quality by producing fog but also may cause frilling or may soften the emulsion to the extent that it will wash off the base.

When it is impossible during extended periods to control the temperature within the most desirable limits, by ordinary methods, the most effective procedure is to cool the solutions by means of electric refrigeration. Processing units designed for use with electric cooling are available commercially.

If it is not feasible to maintain the solutions at 68°F., the development time should be changed as indicated in the table below:

TIME-TEMPERATURE COMPENSATION

Temperature Degrees F.	Development Time in Minutes	
	Normal	Maximum
60	8¾	14
65	6	9½
68	5	8
70	4½	7¼
75	3½	5½

At high temperatures, fixer solution should be renewed frequently, films fixed for fully 10 minutes to insure maximum hardening, and washing time limited to 15 minutes. Short development, effective hardening, and rapid washing all help to prevent excessive softening and swelling of the gelatin of the emulsion. For temperatures above 75°F. (24°C.), further precautions are advisable. Information on high temperature processing is available on request.

Under no circumstances should ice be placed directly in processing solutions to reduce their temperature, because, on melting, the water will dilute them and possibly cause contamination.

Control of Time

Because of the direct relation between temperature and time, both are of equal importance in standardized processing procedure. So, after the temperature of the developer solution has been determined, the films should be left in that solution for the exact interval that is required. Guesswork should not be tolerated. Instead, when the films are placed in the solution, a timer should be set so that an alarm will sound at the end of the development period.

Agitation

It is essential to secure uniformity of development over the whole area of the film. This is achieved by agitating the film or the developer during the course of development.

If films are placed in a developing solution and allowed to develop without any movement, there is a tendency for each area of the film to affect the development of the areas immediately below it. This arises from the fact that the reaction products of development have a higher specific gravity than the developer, and as these products diffuse out of the emulsion layer, they flow downward over the film surface and retard the development of the areas over which they pass. The greater the film density from which the reaction products flow, the greater is the restraining action upon the development of lower portions of the film. Thus, large lateral variations in film density will cause uneven development in the areas below, and this may show up in the form of streaks.

Figure 65 illustrates the phenomena which occur when a film, having small areas whose densities are widely different from their surroundings, is developed without any agitation of film or developer.

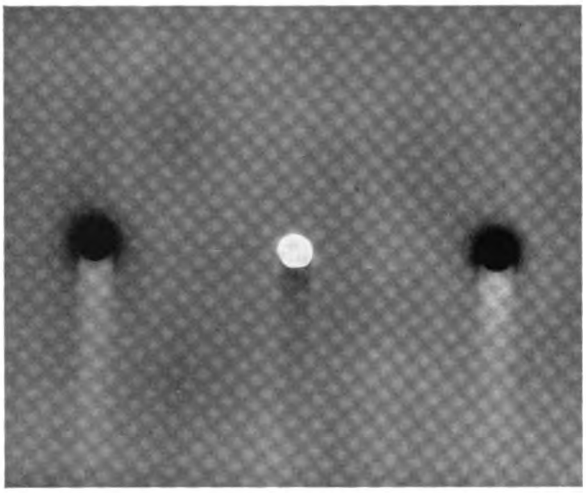


Fig. 65—Streaks resulting from insufficient agitation during development.

Agitation of the film during development, or stirring of the developer, keeps the solution uniform throughout, renews the developer at the surface of the film and prevents this uneven development.

In small installations, where few films are processed, this agitation can most easily be done by hand. Sufficient stirring will result if the films are shaken vertically and horizontally and moved from side to side in the tank for a few seconds every minute during the course of development.

More satisfactory renewal of the developer at the surface of the film will be obtained by lifting the film clear of the developer, allowing it to drain from one corner for 1 or 2 seconds, and then re-inserting it smoothly into the developer. This procedure should be repeated once a minute during the course of development.

As a general rule agitation of the developer by means of stirrers or circulating pumps is to be discouraged. With any tank containing loaded film hangers it is almost impossible to prevent steady flow conditions. The uniform flow of developer along certain paths within the tank may cause more uneven development than no agitation at all.

Since only a slight degree of agitation is needed to eliminate the streaks caused by the reaction products of development, air is considered the most practical means of stirring the developer. Air is allowed to bubble slowly into the tank at the bottom, the rise of the bubbles causing the stirring. One quart of air (at atmospheric pressure) every 5 to 10 minutes will give sufficient agitation to a 5-10 gallon tank of developer. Provided the diameter of the bubbles is greater than ⅛ inch, no trouble will be experienced from oxidation of the developer. The bubbles should rise in such a way as to cause the developer to move past both surfaces of all the films in the tank. The flow of air bubbles sufficient to eliminate the streaking effect of developer reaction products without creating developer flow lines is fairly critical and may require some experimentation under the conditions at hand.

Air obtained from a compressor may be used only if a filter is provided to prevent contamination of the developer with oil or other impurities from the compressor. The most efficient source of air for stirring solutions is a small water-filter pump operating from the tap water supply. Plans for this pump will be sent on request.

The air may most conveniently be introduced into the developer by an open pipe, 5⁄16 inch to ⅜ inch inside diameter, leading down inside one corner of the tank, and reaching to within 2 inches of the bottom. The end of the pipe should be cut square and smooth so that only large bubbles will result. For a 5-gallon tank, a single pipe is usually adequate. Larger tanks may require pipes in two corners. The pipe should be of a material that will not contaminate the developer or cause electrolytic action in a metal tank; hard rubber or Bakelite tubing would meet these requirements most satisfactorily.

Activity of Developer Solutions

As a developer is used, its developing power decreases, partly because of the destruction of the developing agent in changing the exposed silver bromide to metallic silver, and also because of the restraining effect of the accumulated reaction products of the development. The extent of this decrease in activity will depend on the number of films processed and their average density. Even when the developer is not used, the activity may decrease slowly because of aerial oxidation of the developing agent.

Some means must be used to compensate for this decrease in developing power if uniform radiographic results are to be obtained over a period of time. Two methods are available for such a correction, the exhaustion and the replenisher method.

Exhaustion Method

The table on page 68 indicates the development times for *Kodak Industrial X-ray Films* with *Kodak Liquid X-ray Developer and Replenisher* or *Kodak Rapid X-ray Developer* (powders). These times will yield radiographs of the most satisfactory quality; however, these optimum conditions can apply only as long as the solution approximates its original strength. Obviously, the chemicals are gradually exhausted through their action in developing films. Therefore in order to continue to obtain radiographs that are as satisfactory as the initial ones, adjustment to a longer interval must be made to compensate for the progressive diminution of the activity of the chemicals.

In the exhaustion method it is common practice, in removing the films from the developer, to let the excess developer on the film drain back into the tank. Even with this procedure, each 14 x 17-inch film carries with it about 1½ to 2¾ ounces of developer, depending on the time of draining. Although the addition of fresh developer serves to maintain the level of the solution and tends to reduce the effect of exhaustion to some extent, the activity of the developer gradually diminishes with use, at a rate which depends, in part, upon the average density of the radiographs.

Assuming that radiographs of moderate density are being developed in a 5-gallon tank, for the normal time of 5 minutes in the fresh solution, the time of development should be increased to 6 minutes after one hundred 14 x 17-inch films (or equivalent area) have been developed, and to seven minutes after one hundred and fifty 14 x 17-inch films. If eight minutes has been chosen as the time of development in the fresh solution, the time should be increased to 9½ minutes after one hundred 14 x 17-inch films, or equivalent, and to 11 minutes after one hundred and fifty 14 x 17-inch films. If the radiographs are of high density a somewhat greater increase in the time of development will be required.

As a rule the developer should be discarded after the equivalent of one hundred and seventy-five 14 x 17-inch films have been developed in a 5-gallon quantity, since, at this stage, the longer time of development causes undue delay in processing. Furthermore, if exhaustion is carried too far, stains and loss of contrast may result.

Replenisher Method

In the exhaustion method, development time is increased to compensate for exhaustion of the solution. In the replenisher method, through the use of a suitable amount of replenisher, the developing time can be kept practically constant throughout the life of the solution.

When *Kodak Liquid X-ray Developer and Replenisher* is used, the replenisher may be prepared from it according to the directions on the bottle. If *Kodak Rapid X-ray Developer* (powders) is used, *Kodak Rapid X-ray Replenisher* should be obtained for the purpose.

The correct quantity of replenisher required to maintain the properties of the developer constant will depend upon the average density of the radiographs processed. Although the exact quantity required will depend upon the individual conditions, the appended chart shows the approximate amounts of replenisher required for several types of radiographs. It is obvious that if 90 per cent of the silver emulsion is developed, giving a dense image over the entire film, this will use up more developing agents and, therefore, exhaust the developer to a greater degree than if the film were developed to a low density. The quantity of replenisher required, therefore, depends upon the type of subject radiographed, and only average data can be given here.

It is necessary to use a definite system of drainage of the film as it leaves the developer. The replenishers are so compounded that in most cases drainage of the films back into the tank can be omitted. However, in all cases a definite systematic procedure should be adopted so that a fixed quantity of developer is removed for each film developed.

The composition of Kodak replenishers is such that they will maintain the properties of the developers constant when exhausted with films of relatively low average density, the replenisher being added at the rate of 2¾ ounces for each 14 x 17-inch film processed, which is approximately the quantity of developer carried out by each 14 x 17-inch film when drainage of the developer from the film is omitted. For industrial films which may have a relatively large proportion of dense background, the quantity of replenisher should be greater. This will require that *some of the original developer be discarded each time replenisher is added.*

The replenisher should be added at frequent intervals and in sufficient quantity to maintain the activity reasonably constant for the types of radiograph processed. It is obvious that if the replenisher is added only occasionally there will be a large increase in density of the film after replenishing. By replenishing frequently, these density increases after replenishing will be kept at a minimum.

Although the tabulation should be helpful in determining the quantity of replenisher to add, the exact quantity can only be determined by trial and by frequently testing the developer. The quantity of the replenisher added each time should preferably not exceed 2 or 3 per cent of the volume of the developer in the tank.

DEVELOPER REPLENISHER CHART

Type of Radiograph	Approximate Quantity of Replenisher Required For Each 14 x 17-Inch Sheet
1. Low Density Films (less than 15 per cent of the background exposed)	2¾ ounces
2. Medium Density Films (about 40 per cent of background exposed)	3 ounces
3. High Density Films (about 75 per cent of background exposed)	3½ ounces
4. Extremely High Density Films (more than 90 per cent of background exposed)	4 ounces

Obviously, it is not practical to continue replenishment indefinitely, and the solution should be discarded when the replenisher used equals three to four times the original quantity of developer. It is also recommended that the solution be discarded at the end of a three-month period, even though the addition of this amount of replenisher has not been required.

In using *Kodak Liquid X-ray Developer and Replenisher* as a fast developer, the replenisher method can be used, following directions on the bottle. It is recommended that this solution be discarded at the end of a two-week period, even though the suggested amount of replenisher has not been used. Since the use of high speed developer will probably be confined to those laboratories where large volumes of work are done, this apparent short life will not result in any waste of material.

Testing Developer Activity

The success of either method for compensating for the gradual decrease of developer activity will depend upon the use of an adequate system for testing this activity. The easiest way of making the test is to process, at frequent intervals, film strips exposed in some standard manner, and to compare the densities obtained with an identical strip processed in the fresh solution.

The standard strips are cut from a sheet of film, 8 x 10 inches or larger, which has been exposed to direct x-rays through a test object. The most suitable form of test object is a step tablet made up of a number of sheets of any convenient metal. The tablet should have about fifteen steps and be large enough to cover completely the largest cassette or film holder used. When given the proper exposure, this should produce a series of densities which will cover the density range used in practice.

It is essential that all strips used in testing a batch of developer receive identical exposures. For this reason, films are kept in their black paper protective folders during exposure and subsequent storage. No screens of any kind are used. Further, all the sheets of film that will be required must be exposed simultaneously in the same cassette. At 80 kilovolts peak, using an aluminum step tablet, three sheets may be exposed in the same cassette without introducing significant differences in the densities of the top and bottom films. At 180 kilovolts peak, using a steel tablet, five sheets may be exposed at once.

At 1000 KvP., a steel tablet having steps ¼ to ½ inch high may be used, and 5 sheets of film exposed at once. When this penetrating radiation is used a sheet of film should be put in front and in back of the pack that will be used for developer tests. These two outside films are discarded after exposure.

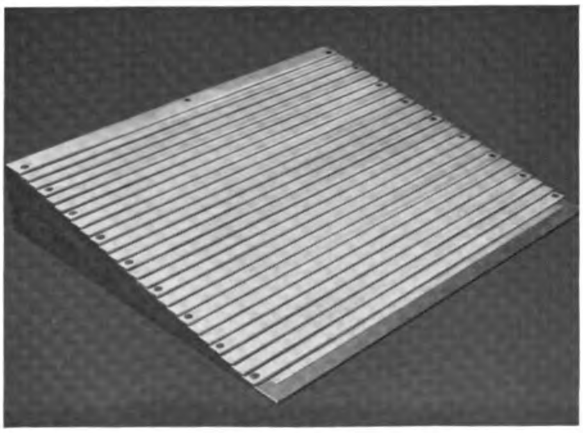


Fig. 66—A step tablet with steps of uniform thickness is a useful accessory in an industrial radiographic department. Step thickness and tablet material will depend upon the voltages at which the tablet is used.

In processing test strips, they should be developed dark end down on regular film processing hangers in the center of the tank and be given the same development time and agitation that will be used in practice.

When a new batch of developer is placed in use, one or more strips are processed and preserved as the standard for comparison throughout the useful life of the developer. Thereafter, a strip should be processed, say, after every fifty 14 x 17-inch films, or equivalent, processed per 5 gallons of developer. If the densities of the test strip are less than those of the strip processed in the fresh solution, the rate of addition of replenisher should be increased, or, if the exhaustion method is used, development time should be increased. If the densities of the test strip are too high, the rate of addition of replenisher or the development time should be decreased.

The step-tablet method of testing developer activity is also useful in cases where the temperature of the processing solutions cannot be exactly controlled. Strips are developed for a series of times, and the development time which gives a strip matching the one developed at 68°F. in fresh solutions is used for routine work.

ARRESTING DEVELOPMENT

After development is complete the activity of the developer remaining in the emulsion must be destroyed by an acid stop bath, or, if this is not feasible, by prolonged rinsing in running water.

If these steps are omitted, development continues for the first minute or so of fixation, and unless the film is agitated almost continuously during this period, uneven development resulting in streakiness will occur.

In addition, if films are transferred to the fixer solution without thorough rinsing or the use of an acid stop bath, the alkali from the developer solution retained by the gelatin will neutralize some of the acid in the fixer solution. After a certain quantity of acid has been neutralized in this way, the chemical balance of the fixer solution is upset and its usefulness is greatly impaired—the hardening action is destroyed and stains are likely to be produced in the radiographs. Removal of as much of the developer solution as possible from the film before fixation prolongs the life of the fixer solution and assures the routine production of radiographs of better quality.

Stop Bath

A stop bath (Kodak Stop Bath SB-1A) consisting of 16 ounces of 28% acetic acid per gallon of bath (125.0 cc per liter) should be used.

When development is complete, the films should be removed from the developer, allowed to drain one or two seconds, and immersed in the stop bath. The developer draining from the films should be kept out of the stop bath. Instead of draining, a few seconds' rinse in fresh, running water may be used prior to inserting the films in the stop bath. This will materially prolong the life of the bath.

Films should be immersed in the stop bath for at least thirty seconds with moderate agitation, and then transferred to the fixing bath.

Five gallons of stop bath will treat about one hundred 14 x 17-inch films, or equivalent. However, the bath should be tested with *Kodak Testing Solution A* of the *Kodak Testing Outfit for Stop Baths and Fixing Baths* after about each twenty 14 x 17-inch films per five-gallon tank. When exhausted, as indicated by the *Kodak Testing Outfit*, the stop bath should be discarded.

A stop bath may be used under any of the usual developing conditions with *Kodak Rapid X-ray Developer* or *Kodak Liquid X-ray Developer and Replenisher* since they contain *Kodalk* rather than sodium carbonate. If a developer containing sodium carbonate is used, the stop bath temperature must be maintained between 65°F. and 68°F.; otherwise blisters containing carbon dioxide gas may be formed in the emulsion by the action of the stop bath.

If glacial acetic acid is used to make the stop bath, three parts of this should be diluted with eight parts of water to make 28% acetic acid. This dilute acid is then used in the formula above. (*Caution:* In using glacial acetic acid, great care must be taken to avoid injury to the skin or damage to clothing.)

Rinsing

If a stop bath cannot be used, a rinse in *running* water for at least two minutes may be used. It is important that the water be running and that it be not contaminated with silver or fixing chemicals. This means that the same tank that is used for the final washing after fixation should not be used for this rinse.

If the flow of water in the rinse tank is only moderate it is desirable to agitate the films carefully, especially on first immersion. Otherwise development will continue unevenly, resulting in streaks in areas which received a uniform exposure.

FIXATION

The purpose of fixation is to remove all of the undeveloped silver salts of the emulsion, thereby leaving the developed silver as a permanent image. The fixer has another important function—the hardening of the gelatin so that the film will withstand subsequent drying with warm air. The interval between the placing of the film in the fixer solution and the disappearance of the original diffuse milkiness is known as the *clearing time.* It is during this time that the fixer is dissolving the undeveloped silver halide. The total *fixing time* should be at least twice the clearing time in order that the dissolved silver salts may diffuse out of the emulsion layer and that the gelatin may be adequately hardened.

When the films are first placed in the fixer solution, and once or twice during fixation, the hangers should be agitated to assure uniform action of the chemicals. *Kodak Industrial X-ray Films, Types M, A, and F,* and *Blue Brand* should be left in the solution for the times indicated in column 3 of the table on page 75. Fixing times for *Type K* and *No-Screen Film* are given in column 4. The temperature should be maintained at about 68°F. (20°C.) in order to preclude abnormal swelling of the emulsion and assure a minimum drying time.

Fixing solutions are offered in powder and liquid forms—*Kodak X-ray Fixer* (powders) and *Kodak Liquid X-ray Fixer and Replenisher* (liquid). The latter offers the same advantages in ease of preparation as the liquid x-ray developer. In addition, it permits a shorter fixing and clearing time to be used than does *Kodak X-ray Fixer* (powders).

Activity of Fixer Solutions

During use, the fixer solution accumulates soluble silver salts which gradually inhibit its ability to dissolve the unexposed silver halide from the emulsion. In addition, the fixer solution becomes diluted by rinse water or stop bath carried over to it by the film. As a result, the rate of fixation decreases, and the hardening action is impaired. The dilution can be partially prevented by thorough draining of films before their immersion in the fixer, and, if desired, the fixing ability can be restored by replenishment of the fixer solution.

The usefulness of a fixer solution comes to an end when it has lost its acidity or when an unusually long interval is required to remove the undeveloped silver salts from the emulsion. The use of an exhausted solution should always be avoided, for abnormal swelling of the emulsion often results from deficient hardening, and drying is unduly prolonged; at high temperatures reticulation or sloughing away of the emulsion may take place. In addition, neutralization of the acid in the fixer solution will frequently cause colored stains on the radiographs.

Unreplenished Fixer Solutions

Sections 1 and 4 of the table on page 75 give the recommended fixing times for the various x-ray films in unreplenished solutions of *Kodak X-ray Fixer* and *Kodak Liquid X-ray Fixer and Replenisher.* As indicated, the fixing time for *Kodak Industrial X-ray Films, Types M, A,* and *F,* and *Blue Brand* is 16 minutes at the limit of the useful life of the unreplenished solution prepared from *Kodak X-ray Fixer* (powders). This point is reached when 150 14 x 17-inch films (or equivalent area) per 5 gallons of solution have been fixed. On the other hand, when a solution made from *Kodak Liquid X-ray Fixer and Replenisher* is used, the fixing time of 15 minutes for these films is not reached until the equivalent of 250 14 x 17-inch films per five gallons of solution have been fixed. (When only 150 films have been fixed, the time will have been increased to but 5 minutes.) It is apparent that with these types of film, the liquid preparation fixes faster and is effective for the fixation of a greater number of films than a solution prepared from the powders.

Because of the heavier emulsions of *Kodak Industrial X-ray Film, Type K,* and *Eastman No-Screen X-ray Film,* their fixation exhausts the fixer solution more rapidly than is the case with the other types. As shown in the table on page 75, the limit of the useful life of the unreplenished solutions prepared from either fixer is reached when the equivalent of 100 14 x 17-inch films have been fixed in 5 gallons of the fixer solution. (The fixing time is 20 minutes at this point.)

Replenishment of Fixer Solutions

A high state of activity of the fixer solution is maintained by the addition of suitable quantities of its constituent chemicals. Two results are achieved: (1) The time required to fix films may be kept at a minimum and the convenience of rapid fixation made continuously available. Thus replenishment of fixing baths enlarges fixing capacity without increasing space requirements. (2) In many cases the useful life of the fixing bath is considerably extended.

Replenishment of Kodak X-ray Fixer Solution

Fixer solutions prepared from *Kodak X-ray Fixer* (powders) may be replenished with suitable quantities of either *Kodak Liquid X-ray Fixer and Replenisher* or a concentrated solution of *Kodak X-ray Fixer.* The following recommendations are based on the use of a 5-gallon quantity of fixer.

Replenishment with Kodak Liquid X-ray Fixer and Replenisher

(See section 2 of table on next page)

When 50 14 x 17-inch films, or their equivalent, have been fixed in 5 gallons of solution, a full quart of the partially exhausted solution is removed from the tank, and replaced with 1 quart of *undiluted Kodak Liquid X-ray Fixer and Replenisher* (*Solution A*) and 4 ounces of *Kodak Hardener* (*Solution B*). This means that the entire contents of a small-sized bottle (used for making 1 gallon of conventional fixer) of *Kodak Liquid X-ray Fixer and Replenisher,* and the entire contents of the accompanying 4-oz. bottle of *Kodak Hardener* (*Solution B*) are used for the purpose.

Four such replenishments are recommended when *Types M, A, F* and *Blue Brand* films, and perhaps small amounts of *Type K* and *No-Screen* films, are processed. Only *two* replenishments are possible when *Type K* and *No-Screen* films exclusively are processed. After the fixer solution has been replenished the recommended number of times, it should be employed up to the desired degree of exhaustion (as determined by the clearing time) and then discarded. It is recommended that a clearing time of eight minutes, and therefore a fixing time of about 15 minutes, be considered the practical limit of the useful life of a fixer solution that has been replenished four times for the processing of *Types M, A, F* and *Blue Brand Films.*

Replenishment with Concentrated Solution of Kodak X-ray Fixer

(See section 3 of table on next page)

A solution prepared from *Kodak X-ray Fixer* (powders) may be replenished by the addition of a suitable quantity of concentrated solution made from *Kodak X-ray Fixer* itself. The recommended procedure for this type of replenishment is as follows: When 50 14 x 17-inch films have been fixed in 5 gallons of solution, remove 2 quarts of partially exhausted fixer from the tank and replace it with 2 quarts of a concentrated solution made from *Kodak X-ray Fixer* (powders). This concentrated solution is prepared by mixing the contents of a

FIXER EXHAUSTION CHART

FIXER SOLUTION	Number of 14"x17" films processed per 5 gals. of solution	Fixing Time (in minutes)	
		Types M, A, F Blue Brand	Type K No-Screen
Section 1 Kodak X-ray Fixer (powders)	0	5	10
	50	6	12
	100	10	20
	150	16	—
Section 2 Kodak X-ray Fixer replenished with Kodak Liquid X-ray Fixer and Replenisher	0	5	7
	50	5	10
	100	5	16
	150	5	20
	200	5	—
	250	6	—
Section 3 Kodak X-ray Fixer replenished with concentrated solution of Kodak X-ray Fixer	0	5	10
	50	5	12
	100	5	16
	150	6	22
	200	7	—
	250	8	—
Section 4 Kodak Liquid X-ray Fixer and Replenisher	0	3	7
	50	3	10
	100	4	20
	150	5	—
	200	8	—
	250	15	—
Section 5 Kodak Liquid X-ray Fixer and Replenisher replenished with Kodak Liquid X-ray Fixer and Replenisher	0	3	7
	50	3	10
	100	3	16
	150	3	20
	200	3	—
	250	4	—

1-gallon size container of the fixer powders in 5 pints of water. This solution is highly concentrated and at temperatures lower than 70°F., crystals may be deposited. These can be redissolved by raising the temperature of the solution.

Kodak X-ray Fixer solution used to process *Kodak Industrial X-ray Film*, *Types A*, *M*, *F*, and *Blue Brand* may be replenished 4 times with its own concentrated preparation. When used to process *Type K Film* and *No-Screen Film* exclusively, it may be renewed only twice. Recommendations for discarding this solution are the same as for solutions prepared from *Kodak X-ray Fixer* (powders) that are replenished with *Kodak Liquid X-ray Fixer and Replenisher.*

Replenishment of Kodak Liquid X-ray Fixer Solution

(See section 5, table on this page)

Fixer solutions prepared from *Kodak Liquid X-ray Fixer and Replenisher* should be replenished only by undiluted *Kodak Liquid X-ray Fixer and Replenisher* itself; no other replenisher is recommended. The procedure is the same as that described for the replenishment of *Kodak X-ray Fixer* solution by undiluted *Kodak Liquid X-ray Fixer and Replenisher.* (See page 74.)

WASHING

X-ray films should be washed in running water that is so circulated that the entire emulsion area will receive frequent changes. For proper washing, the bar of the hanger and the top clips should always be covered completely by the running water, as illustrated in Figure 67.

Efficient washing of the film depends both on a sufficient flow of water to carry the fixer away rapidly, and on adequate time to allow the fixer to diffuse from the film. To wash the various types of Kodak industrial x-ray film, the hourly flow of water should not be less than 12 times the volume of the tank, and the time of washing should be at least 20 minutes.

The films should be placed in the wash tank near the outlet end. Thus, films which are most heavily laden with fixer are first washed in water which is somewhat contaminated with fixer from the films previously put in the wash tank. As more films are put in the wash tank, those already partially washed are moved toward the inlet, so that the final part of the washing of each film is done in fresh, uncontaminated water.

The tank should be large enough to wash films as rapidly as they can be passed through the other solutions. Any excess capacity is wasteful of water and diminishes the effectiveness with which hypo is eliminated from the film emulsion. Too small a washing capacity encourages insufficient washing which may lead to later discoloration or fading of the image.

The "cascade method" of washing is the most economical of water and gives better washing for the same length of time. In this method, the washing compartment is divided into two sections. The films are taken from the fixing bath and first placed in compartment A (Figure 68). After they have been washed partially, they are moved to section B, leaving A empty to receive more films from the fixer. Thus, films heavily laden with fixer are washed in somewhat contaminated water, and the partially washed films complete their washing in fresh water.

The hourly flow of water should be at least six times the volume of one compartment, and the time of washing should be at least 10 minutes in each compartment.

Under warm weather conditions, it is especially important to remove the films from the tank as soon as washing is completed, as gelatin has a natural tendency to soften considerably with prolonged washing in water above 68°F.

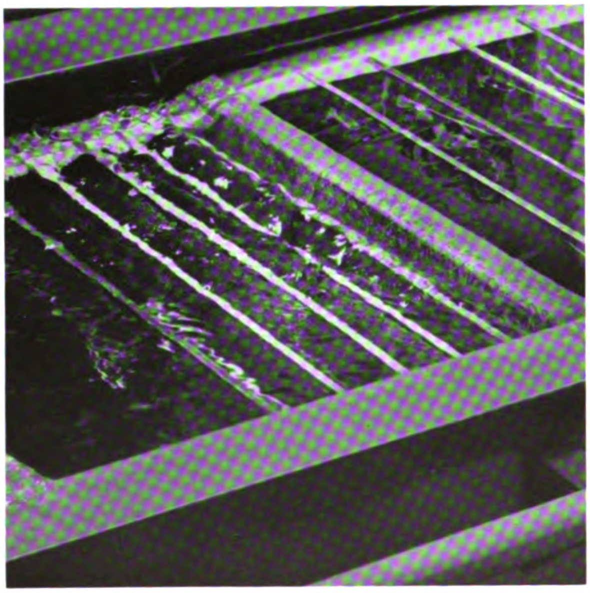


Fig. 67—Water should flow over the tops of the hangers in the washing compartment.

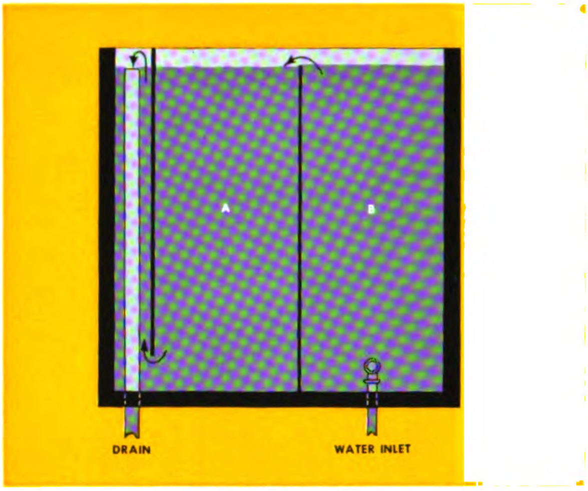


Fig. 68—Schematic diagram of a cascade washing unit.

PREVENTION OF WATER SPOTS

When films are removed from the wash tanks, small drops of water cling to the surfaces of the emulsions. If the films are then dried rapidly, the areas under the drops dry more slowly than the surrounding areas. This uneven drying causes distortion of the gelatin, changing the density of the silver image, and results in spots which are frequently visible and troublesome in the finished radiograph.

Such "water spots" may be largely prevented by immersing the washed films for one or two minutes in a solution of *Kodak Photo-Flo* and allowing to drain for one or two minutes before placing in the drying cabinet. The action of this solution causes the surplus water to drain off the film more evenly, reducing greatly the number of clinging drops. This decreases the drying time and greatly reduces the number of water spots in the finished radiograph.

DRYING

Where only a small number of films are processed daily, a convenient rack for holding hangers during drying can be made by drilling ⅜-inch holes about 4 inches apart in a 1 x 3-inch board as long as desirable. When the rack is placed high on the wall the films can be suspended by inserting the crossbars of the developing hangers in the holes. This obviates the danger of striking the radiographs while they are wet, or spattering water on the drying surfaces, which would cause spots on them. Radiographs dry best in warm, dry air that is changing constantly.

For processing rooms where a considerable number of films are to be processed, suitable dryers with built-in fans, filters, and heaters, are commercially available.

TRAY PROCESSING

This method is not as efficient as the tank system of processing. However, when circumstances are such that a tank installation is not available, satisfactory results may be obtained by employing trays and exercising the necessary care.

Several durable white-enameled, hard rubber or glass trays are essential. They should be of adequate size to accommodate the largest film that is used. *Kodak Enameled Trays* are made especially for processing, and there is a choice of sizes to meet every requirement.

One tray is used for developer solution, another for stop bath or rinse water, a third for fixer solution, and a fourth for wash water. The tray for washing should be fitted with a *Kodak Automatic Tray Siphon*, so that the water will be kept in constant circulation.

In the tray system, a quantity of solution should be mixed at regular intervals and kept in brown bottles or glazed jugs. Then a sufficient amount to cover the films to a depth of at least 1 inch is poured into the proper trays just before processing.

When the film is removed from the cassette or film holder, a *Kodak Dental Film Clip* should be attached to one corner to facilitate handling. The film is then immersed in the developer solution by a quick sliding motion. If the emulsion is not covered evenly, a dark line where the solution pauses will show in the radiograph. Likewise, dark spots will develop on the film at points where spattered drops of developer strike the dry emulsion. During development, the film should be moved about frequently so that the underside does not adhere to the tray and thereby retard the action of the chemicals. The tray also should be rocked in an irregular manner to provide continual mixing and redistribution of the solution over the entire surface of both emulsions of the film.

Films should be developed for the usual interval, and rinsed, fixed, and washed according to the routine for the tank method.

MARKS IN RADIOGRAPHS

Defects, spots, and marks of many kinds may occur if the preceding general processing rules are not carefully followed. Perhaps the most common processing defect is streakiness and mottle in areas which received a uniform exposure. This unevenness may be a result of:

A. Failure to agitate the films sufficiently during development or the use of too many hangers in the tank resulting in insufficient spacing between the films.

B. Insufficient rinsing in water or failure to agitate the films sufficiently before fixation.

C. The use of an exhausted stop bath or failure to agitate the film sufficiently in the stop bath.

D. In the absence of satisfactory rinsing—insufficient agitation of the films on first immersion in the fixing bath.

Other characteristic marks are dark spots caused by the spattering of developer solution, static electric discharges, and finger marks; and dark streaks occurring when the developer-saturated film is inspected for a prolonged time before a safelight lamp. When it is possible to avoid it, films should never be examined at length until they have been dried.

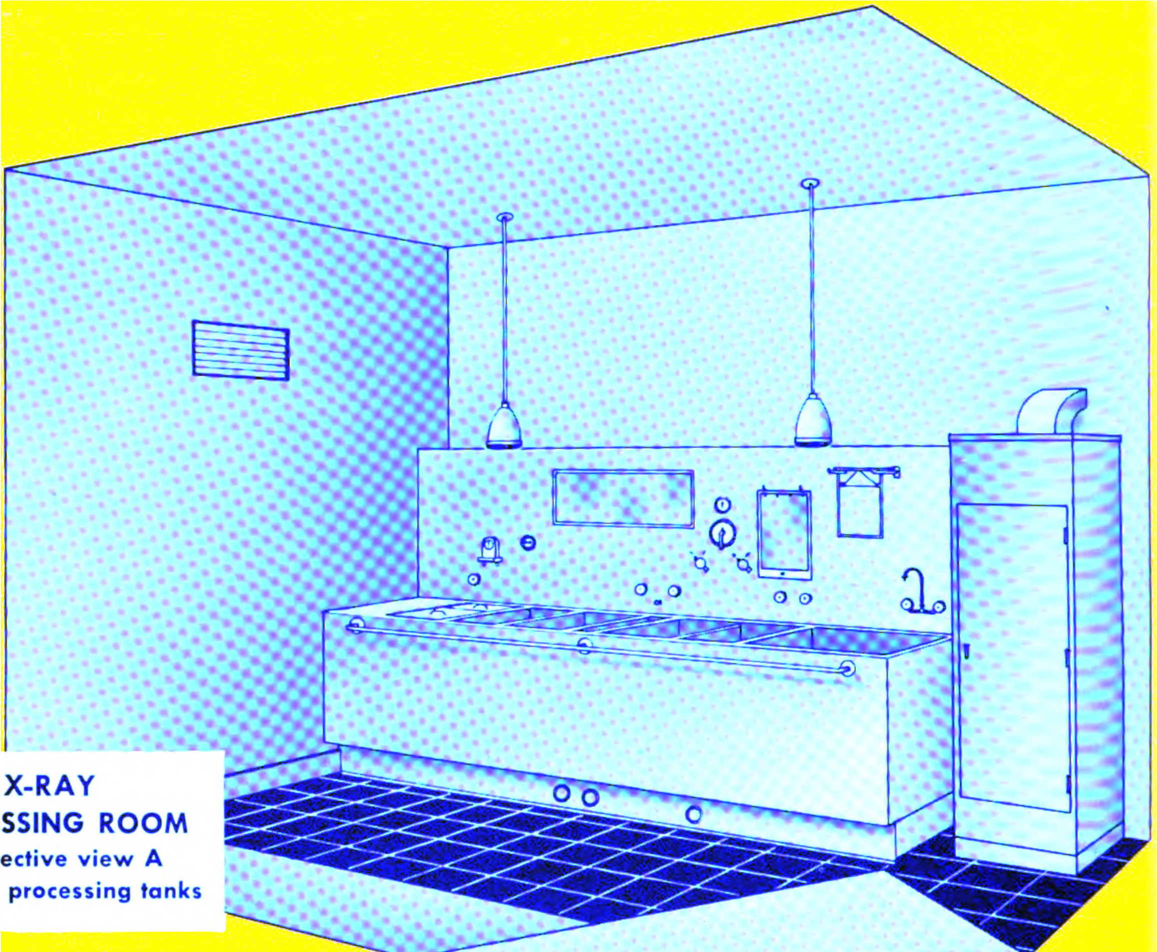
A further trouble is fog—i.e., a development of silver particles other than those affected by radiation during exposure. It is a great source of annoyance and may be caused by accidental exposure to light, x-rays, or radioactive substances; contaminated developer solution; development at too high a temperature; or keeping films under improper storage conditions or beyond the expiration date stamped on the cartons. A common occurrence is accidental exposure of the film to x-radiation, because of insufficient protection from high-voltage tubes; films have been fogged through ⅛ inch of lead in rooms 50 feet or more from the tube.

FILING RADIOGRAPHS

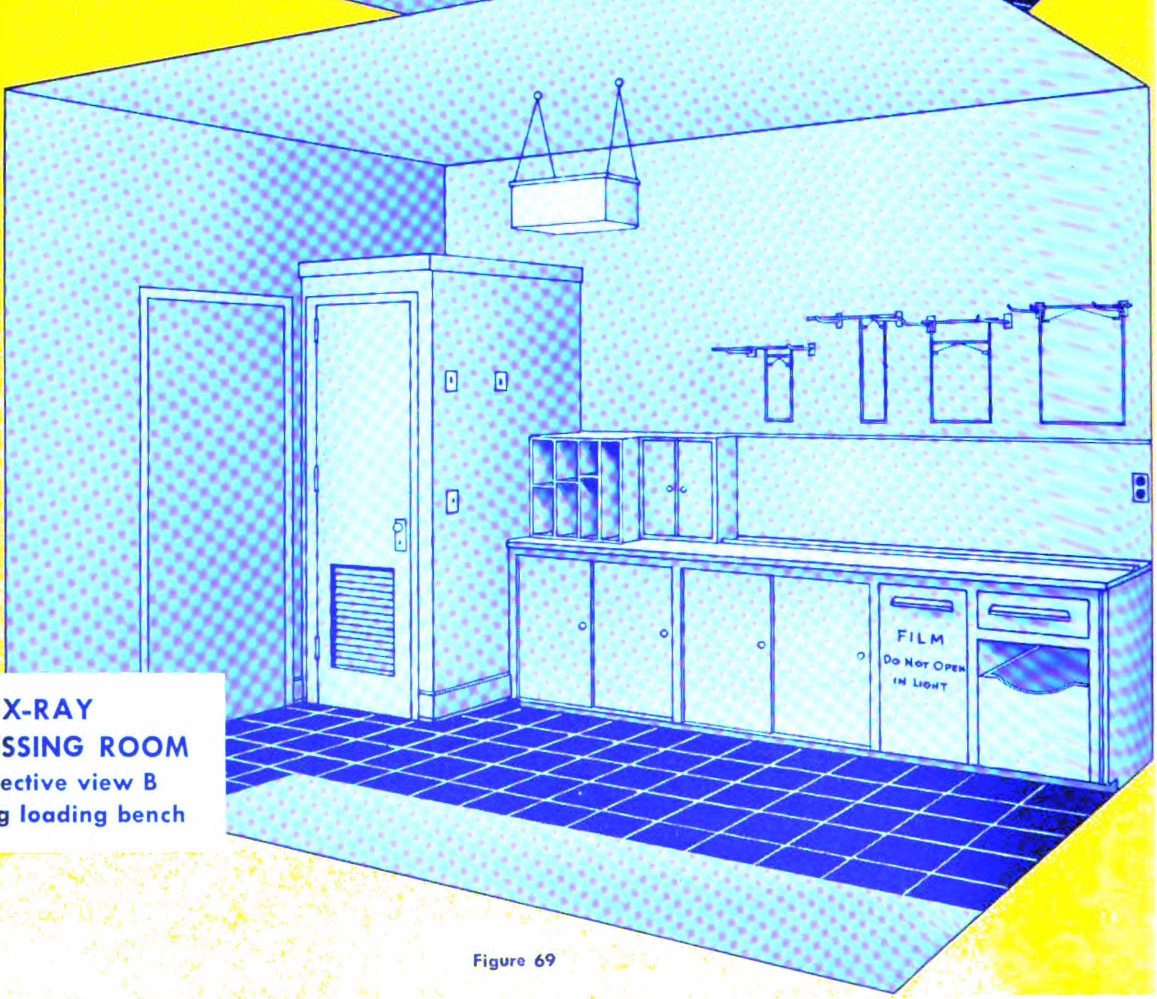
After the radiograph is dry it must be prepared for filing. The first step is the elimination of the pointed corners and the sharp projections that are caused by the film-hanger clips. This can easily be done with the *Kodak X-ray Corner Cutter*, and it will enhance the appearance of the radiograph, preclude its scratching others with which it may come in contact, facilitate its insertion into an envelope, and conserve filing space.

As soon as the corners have been trimmed, the radiograph should be placed in a heavy manila envelope of proper size, and all of the essential identification data should be written on the envelope so it can be easily handled and filed.

The storage of radiographs does not present any unusual fire hazard. (See page 63.)



X-RAY PROCESSING ROOM
Perspective view A
showing processing tanks



X-RAY PROCESSING ROOM
Perspective view B
showing loading bench

Figure 69

THE PROCESSING ROOM

Too much thought cannot be given to the proper planning of the processing room. In order that the exposed films may be manipulated expeditiously and that the highest possible photographic quality in the radiographs may be obtained regularly, this room should be completely equipped in every detail. It is hardly consistent to invest thousands of dollars in efficient x-ray equipment and not to give due consideration to the provision of adequate space and apparatus for processing the films.

DESIGN OF THE PROCESSING ROOM

In assigning space for the processing room, proper consideration should be given to the volume of work to be processed. Figures 69 and 70, pages 78 and 80, show the floor plan and side elevations of a darkroom in which thirty 14 x 17-inch films can be processed per hour. Detailed plans of this darkroom and its equipment are available on request from the Eastman Kodak Company. Assuming a normal developing time of five minutes, one 5-gallon tank will develop thirty films an hour. The capacity of the stop-bath compartment should be about that of the developing tank. The capacity of the fixing-bath compartment should be approximately twice that of the developing tank, or 10 gallons. The wash tank should hold from 20 to 25 gallons and the direction of flow of water should be such that the films removed from the fixer are placed in the wash tank at the *outlet* end. With this as a basis, it is a simple matter to determine how much the processing room facilities should be increased to accommodate more films.

In the interest of efficiency, the floor space should be as small as practical, and the arrangement in general should follow the plans shown. This keeps dry films, holders, and cassettes away from the solutions, and eliminates many accidents, due to careless handling, which may damage sensitive material.

Processing rooms generally have a labyrinth, or lighttight vestibule. This is necessary if access is to be extended to all who are handling films. If, however, the processing is to be done by one person, a single door, which can be locked on the inside, will be sufficient.

The processing room should, if possible, adjoin the x-ray room, and have a lead-protected film-transferring cabinet in the wall between. This makes loaded holders and cassettes easily available to the operator, and the exposed film can be passed through to the processing room. This reduces traffic in the darkroom, and permits the work there to be carried on without interruption.

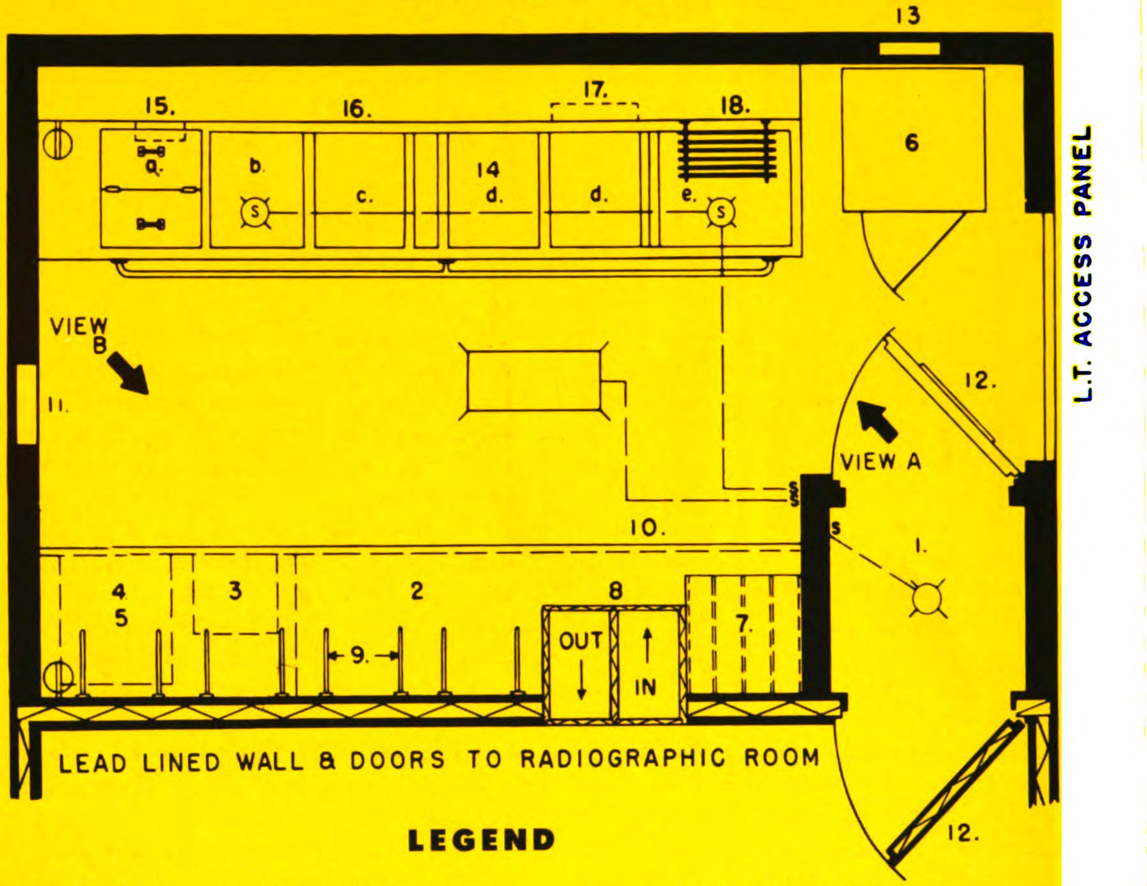
Proper ventilation of the darkroom is important. To assure constant circulation of clean, fresh air, and thus make the processing room more healthful, and the routine less fatiguing, one or more *Eastman Darkroom Ventilators* should be installed—the number depending upon the size of the room.

The film bins illustrated in these plans are commercially available and provide an ideal place to store opened boxes from which holders are loaded. They are lighttight, close automatically, and make film easily available for most efficient loading.

The drying of films is always important; therefore, considerable attention should be paid to film-drying cabinets. Suitable dryers are commercially available. The air intake should be fitted with a filter and heating elements. The exhaust fan should be as large as practical. As a precaution, the heating elements should be connected in the fan circuit to prevent turning on the heat without also turning on the fan. Incidentally, the arrangement shown is also helpful in the ventilation of the processing room.

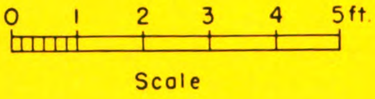
In addition to the equipment listed above, it is suggested that two white enamel pails, several glass funnels, and two wooden paddles about 36 inches long be provided for mixing, pouring, and stirring

LAYOUT PLAN



LEGEND

1 LIGHT LOCK WITH LIGHT TIGHT DOORS
2 LOADING BENCH
3 FILM STORAGE BIN
4 LIGHT TIGHT DRAWER
5 WASTE BIN
6 FILM DRYER
7 CASSETTE STORAGE
8 CASSETTE PASS BOX
9 FILM HANGERS (STORAGE)
10 SUPPLY CABINET
11 AIR SUPPLY DUCT
12 LIGHT TIGHT LOUVRE
13 AIR EXHAUST FROM FILM DRYER
14 X-RAY PROCESSING TANK
  a. DEVELOPING TANKS
  b. ACID STOP BATH
  c. FIX
  d. WASH (CASCADE)
  e. SINK
15 ELECTRIC TIMER
16 CHART BOARD
17 ILLUMINATOR
18 FILM HANGERS (DRAINING)



FOR VIEWS A AND B SEE PAGE 78

X-RAY PROCESSING ROOM

ELECTRICAL

▭	INDIRECT LIGHT BOX (DOUBLE)
Ⓢ	DARKROOM LAMP
⊗	CEILING FIXTURE (RUBY LAMP)
⊖	CONVENIENCE OUTLET
S	SWITCH

Figure 70

processing solutions. Several water- and chemical-proof *Kodak Darkroom Aprons* also should be available to protect the clothing of those working in the room.

FINISH

It is highly desirable that the finish of the processing room be carefully chosen, for two distinct requirements must be met. The floor, benches, and walls to at least a few inches above the tanks and benches should be thoroughly protected against the action of chemical solutions and water that may be spilled or splashed on them. The upper walls and ceiling should be painted a pleasing light color so that the maximum safe illumination will be reflected from them.

ILLUMINATION

In so far as possible, the general illumination should be indirect. This can be accomplished by suspending from the ceiling one or more *Kodak Utility Safelights*; with the walls and ceiling painted according to the preceding recommendations, the entire room will be well lighted with safe illumination.

For light in specific sections of the processing room, *Wratten*, *Kodak*, and *Brownie Safelight Lamps* are most efficient. The choice and arrangement should depend upon the amount of illumination desired and the angle at which it must fall.

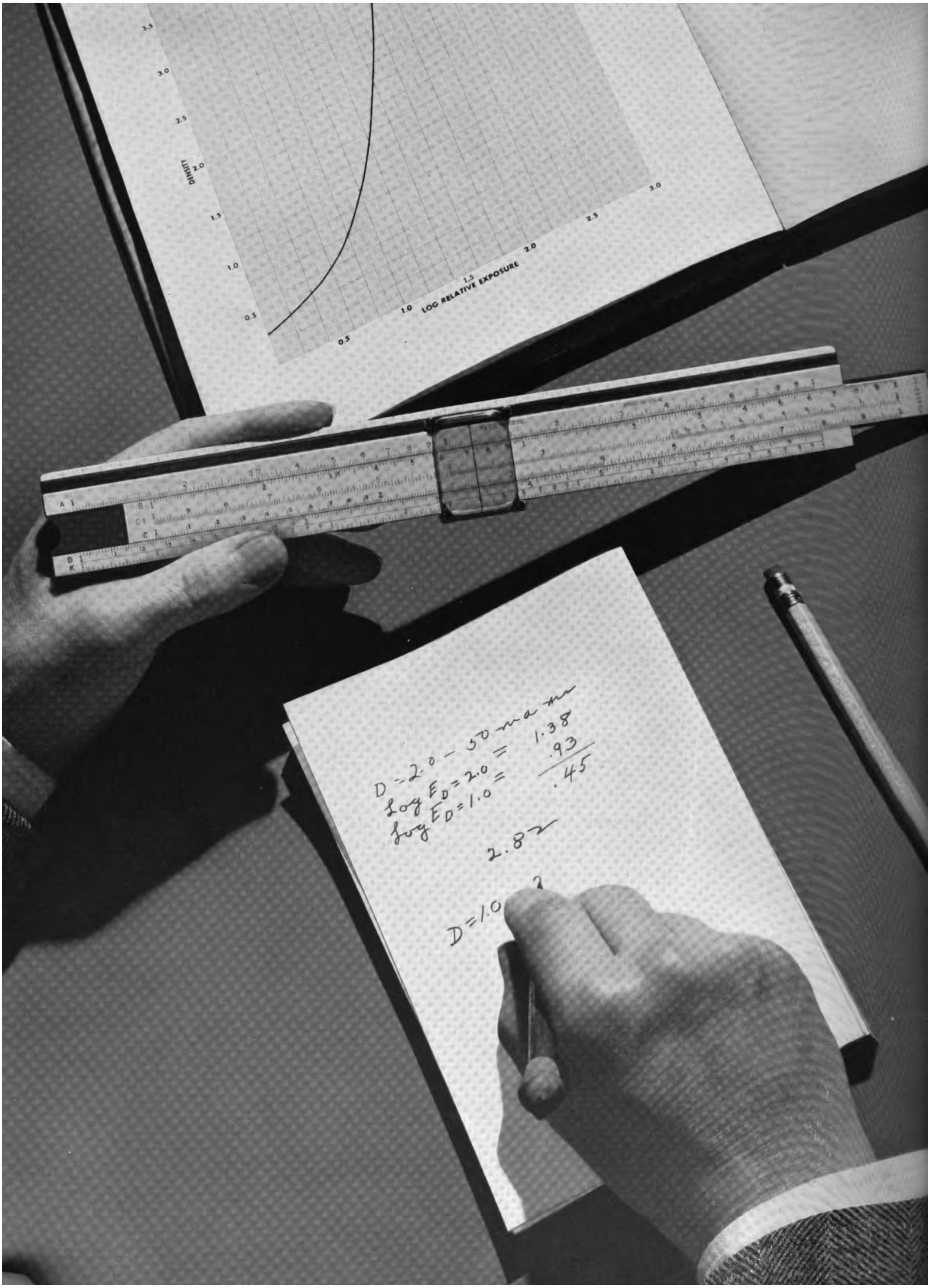
Wratten Safelights, *Series 6B*, are recommended for use in indirect light boxes and all safelight lamps—indirect type for the former and direct type for the latter. They provide maximum illumination, to which the eyes easily adapt themselves, so that every operation can be carried out by sight.

Checking Safety of Illumination

Certain considerations must be kept in mind in connection with safelight lamps and safelights. First, the illumination will be safe only if bulbs of the wattage indicated on each safelight lamp are used. Second, all safelight filters are safe only as long as the specified conditions prevail. The standard of safety for all *Wratten Safelights* is such that unexposed sensitized materials for which they are recommended may be handled in the light at a distance of 3 feet, for 1 minute; at 2 feet, for ½ minute; and these factors apply to the use of *Wratten Safelights*, *Series 6B*, with x-ray film. Exposed films are more sensitive to the illumination from safelight lamps than are unexposed films, so it is important when loading them in hangers preparatory to group development that they be safeguarded against direct light from the lamps. It may be convenient to store loaded hangers temporarily in the shadow of a shelf which overhangs part of the loading bench. Since the emulsions are less sensitive when wet, the films may be exposed to the light for longer periods after having been immersed in the developer solution.

The screen-type films (*Type F* and *Blue Brand*) are more sensitive to fogging from safelights both before and after exposure. Direct-exposure films possess greater latitude against fogging under darkroom safelights.

A simple method of checking the safety of illumination is to cover part of a film and expose the remainder for different lengths of time in the place where films will be uncovered in handling, and then to give this test film standard development. If no density shows on the parts that received a reasonably long exposure, as compared with the covered part, the lighting may be assumed to be safe.


DENSITY
3.5
3.0
2.5
2.0
1.5
1.0
0.5
LOG RELATIVE EXPOSURE
0.5
1.0
1.5
2.0
2.5
3.0
A
B
CI
C
D
K
D = 2.0 – 50 ma ma
Log E D=2.0 = 1.38
Log E D=1.0 = .93
.45
2.82
D=1.0 2

APPENDIX I

THE SENSITOMETRIC CHARACTERISTICS OF INDUSTRIAL X-RAY FILMS

When a radiograph is exposed, x-rays (or gamma rays) are projected through the object, forming a species of shadow image on the film. The two most important qualities of the image are sharpness of outline and the variations in x-ray intensity from one area to another, as governed primarily by the differences in absorption of the x-rays by different portions of the object.

The x-ray image thus formed is not observed directly, but through the intermediary of the x-ray film. Obviously, the manner in which the film reproduces the incident x-ray image is a vital factor in both radiographic technic and interpretation. The photographic process may modify the image in several ways. This discussion will deal only with the photographic rendition of the various x-ray *intensities* in the image.

In viewing a radiograph against an illuminator, the different intensities in the x-ray image are observed as differences in the amount of light transmitted by the various areas in the radiograph. What is the degree of correspondence between the x-ray intensities in the original image and the resulting intensities of light seen in the radiograph? Does the radiographic reproduction alter the intensity relations in the x-ray image and, if so, in what way? Are such modifications advantageous or otherwise, and what may they indicate as to choice of technic? In viewing a radiograph, what mental corrections must be applied in order to judge properly the character of the original x-ray image?

These questions may be answered by the experimental determination of the relationship between x-ray intensities in the image and light intensities in the illuminated radiograph. Such a relationship is commonly expressed in the form of a curve or graph. In developing the basis for the selection of the proper type of graph and for its interpretation, the use of simple algebra will be required. The essential concepts will first be defined, and a series of imaginary or hypothetical cases will be examined.

In exposing a radiograph, the duration of the exposure, as well as the intensity of the image, contributes to the effect upon the film. The two factors of x-ray intensity (I_x) and exposure time (t) may be grouped together ($I_x \times t$) to form a quantity called the *exposure* (E). (See also pages 13 and 14.)

When viewed against an illuminator, the various areas of the radiograph transmit different fractions of the incident light. If I_o represents the intensity of the light falling on an area of the film, and I_t the intensity of the light passing through it, $\frac{I_t}{I_o}$ is the fraction transmitted, and is called the *transmittance*.

Photographic density is a measure of the degree of blackening of a photographic deposit. The greater the blackening, that is, the less the light transmitted, the greater is the density. Density (D) is defined by the following equation: (See also page 33.)

$$D = \log \frac{I_o}{I_t} \qquad (1)$$

In this definition, the common logarithm (to the base 10) is intended. This specification of density accords with the tendency of the eye to judge relative intensities of light more in proportion to the logarithm of the intensity than to the intensity itself.

Let us assume first that the radiograph reproduces exactly, in the relative intensities of the transmitted light, the variations in exposure produced by the different intensities in the x-ray image. In other words, the fraction of the light transmitted by any area of the radiograph is directly proportional to the original x-ray exposure on that area. In mathematical language, this relation may be expressed:

$$\frac{I_t}{I_o} = kE \qquad (2)$$

where k is a constant of proportionality. The constant k in this and subsequent equations is employed merely to put the assumed proportion into the form of an equation. It can have any numerical value without affecting the validity of the discussion. This case represents a *positive* radiograph, in which the more intense portions of the x-ray image are represented by the brighter portions of the radiograph.

In practice, however, radiographs are *negative* images, in which the darker areas are those which received the more intense portions of the x-ray image. For this case, we shall assume a simple inverse relation between the transmitted light and the original x-ray exposure. According to this relation, if portion *A* of the x-ray image has double the exposure of portion *B*, the corresponding portion *A* of the radiograph will transmit half as much light as portion *B*. For example, the various areas of the image might have x-ray intensities in the ratios 1, 2, 5, 8, 15, and 37. Corresponding areas in the radiograph would transmit light in the ratios 1, $^1/_2$, $^1/_5$, $^1/_8$, $^1/_{15}$, and $^1/_{37}$. Mathematically, this relationship is expressed by the equation

$$\frac{I_t}{I_o} = \frac{k}{E} \qquad (3)$$

According to this relation, a 2 per cent *increase* in x-ray exposure would be recorded as a 2 per cent *decrease* in light intensity.

Taking the logarithm of both sides of equation (3),

$$\log \frac{I_t}{I_o} = \log k - \log E \qquad (4)$$

or

$$\log \frac{I_o}{I_t} = \log E - \log k \qquad (5)$$

The left side of this equation represents the definition of density. Equation (5) may now be written

$$D = \log E - \log k \qquad (6)$$

This relation between density and exposure is another way of stating the assumption that the transmission of light by an area of the radiograph

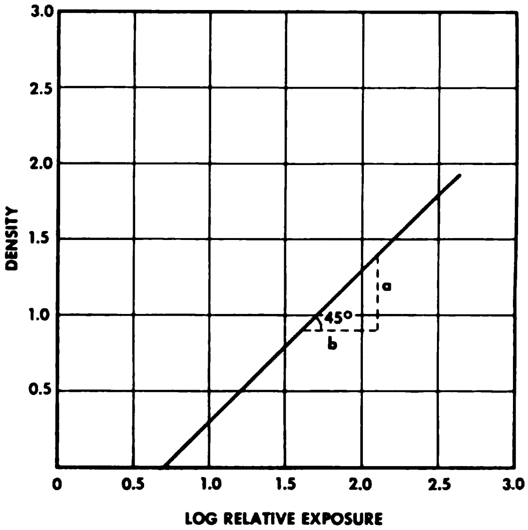


Figure 71

is inversely proportional to the original exposure on that area. This relation is also expressed graphically in Figure 71. This graph is a straight line making an angle of 45 degrees with the log E (logarithm of exposure) axis. The slope of this line (ratio $\frac{a}{b}$ of the sides of the triangle) is 1.0.

Now let us modify equation (6) by introducing the coefficient 3 before the term *log E*. We get

$$D = 3 \log E - \log k. \qquad (7)$$

The graph of this equation is shown at *M* in Figure 72. This is also a straight line, but with a slope (ratio $\frac{a}{b}$) of 3. According to this relation, if area *A* of a radiograph received twice as much exposure as area *B*, *A* would transmit ⅛ as much light as the area *B*. A 2 per cent difference in image intensity would be reproduced as a 6 per cent difference in the transmission of light. Thus, the ratio of intensities or exposures in the x-ray image is no longer rendered as a simple inverse ratio in the radiograph, but has been greatly increased.

Another case is illustrated by graph *N* in Figure 72, whose slope is 0.5. With this relationship between density and exposure, an intensity ratio of 2 to 1 in the image is reproduced as a transmission ratio of 1 to 1.4 in the radiograph, and a 2 per cent intensity difference in the image is recorded as a 1 per cent transmission difference in the radiograph. In this example, intensity ratios in the x-ray image

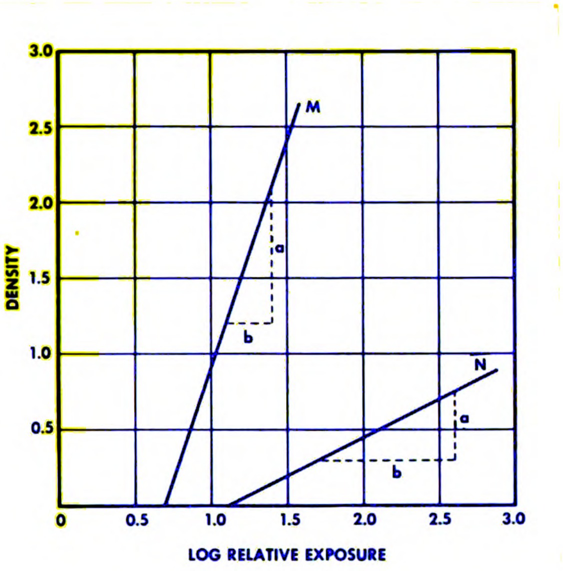


Figure 72

are diminished in the radiographic reproduction.

Calculation shows that if the slope of the graph of D versus log E is greater than 1.0, intensity ratios or contrasts in the subject are exaggerated in the radiographic reproduction, and the greater the slope, the greater is the degree of exaggeration. Similarly, if the slope of the graph is less than 1.0, subject contrasts are diminished in the radiographic reproduction.

The above examples all represent hypothetical cases. An actual graph of D versus log E for *Kodak Industrial X-ray Film, Type A*, is shown in Figure 73. This graph is not a straight line, but curves continuously throughout its length. Slope values for several short sections of the graph are shown diagrammatically. For example, over the density range 0.4 to 0.7, the effective slope (ratio $\frac{a}{b}$) is 0.8. This value is less than 1.0. Therefore, in this density range, subject contrasts are decreased in the radiograph, whereas, at the higher densities, the subject contrasts are increased. For instance, in the density range 1.6 to 2.2, the effective slope is 3.9.

The ability of the film to increase the contrast of the x-ray image is of the utmost practical importance. Otherwise, many faint differences in the subject could not be made visible. This gain in contrast is utilized in practically all industrial radiography. It is especially significant in radiography with gamma rays and million-volt x-rays, where the

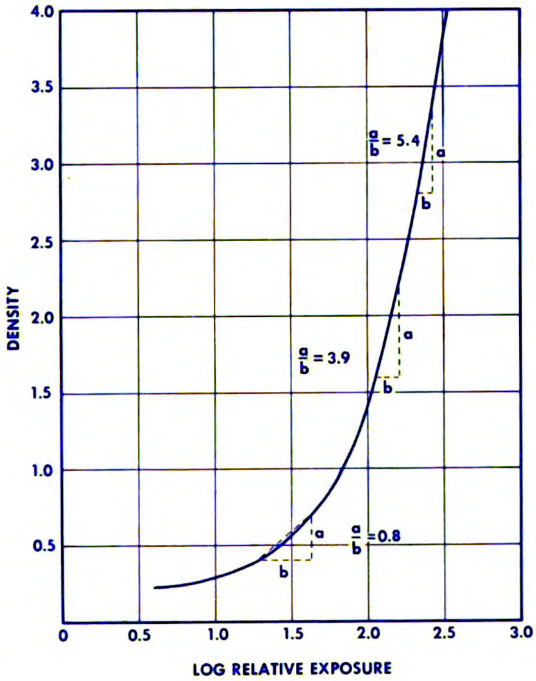


Fig. 73—Characteristic curve of *Kodak Industrial X-ray Film, Type A*, showing effective slopes over several density ranges.

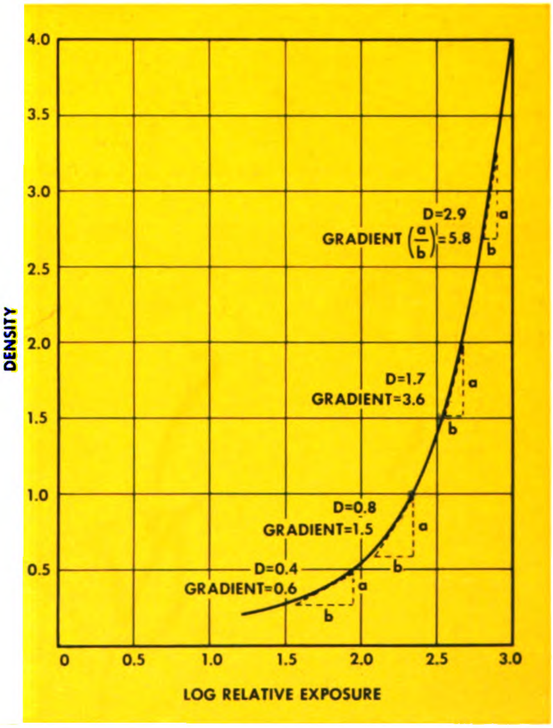


Fig. 74—Characteristic curve of *Kodak Industrial X-ray Film, Type M*. Tangents are drawn at several points to evaluate the gradient.

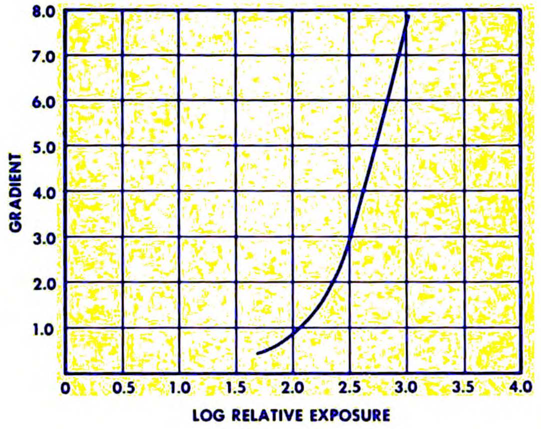


Fig. 75—Gradient vs. log exposure curve for *Kodak Industrial X-ray Film, Type M.*

high penetration of the rays produces low subject contrasts. High radiographic sensitivity depends directly on the enhancement of subject contrast by the film.

The graph of density versus logarithm of the exposure is called the characteristic curve, the sensitometric curve, or the H. and D. curve, after Hurter and Driffield, who devised this method of expressing the properties of a photographic material.

A straight line drawn tangent to a curve at any point has the same slope as the curve at this point (Figure 74) and this slope may be evaluated by determining the ratio $\frac{a}{b}$. The slope at a single point on the curve is commonly called the gradient. In this curve, the gradient increases continuously with increasing density.

In Figure 75, the gradient of the curve in Figure 74 is plotted against log exposure, and in Figure 76, the gradient is plotted against density. The gradient of this film is seen to increase steadily up to the highest densities (about 4.0) that can be utilized with available high intensity illuminators. Thus, within the usable density range, this film gives its highest magnification of subject contrast, and therefore its best differentiation of detail and greatest radiographic sensitivity, in the higher densities.

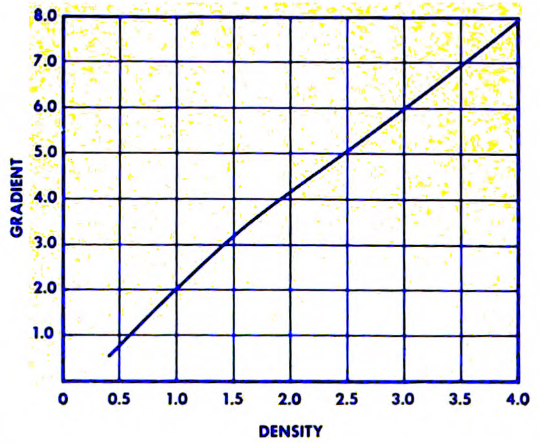


Fig. 76—Gradient vs. density curve for *Kodak Industrial X-ray Film, Type M.*

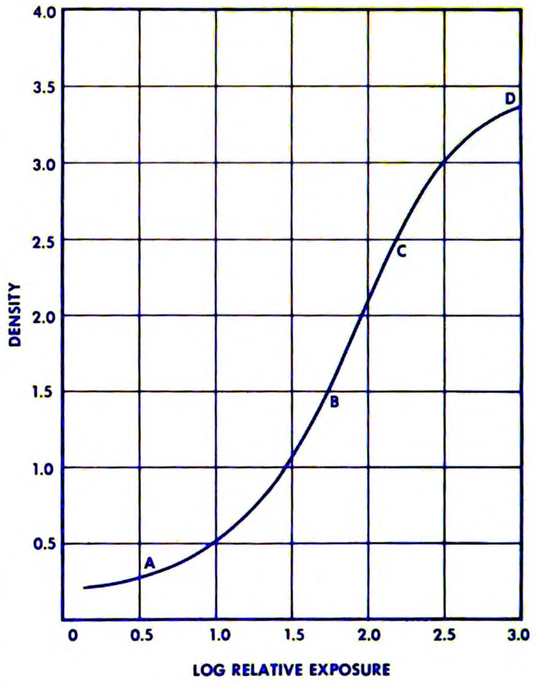


Fig. 77—Characteristic curve of *Kodak Industrial X-ray Film, Type F,* exposed to direct x-rays.

The film gradient is the factor by which small percentage differences in image intensity are multiplied in the radiographic reproduction. For example, a gradient of 3 increases a 2 per cent x-ray intensity difference to a 6 per cent difference in transmitted light, while a gradient of 5 increases a 2 per cent x-ray intensity difference to 10 per cent.

Most industrial radiography utilizes film gradients higher than 1.0. Some x-ray films are more contrasty than others and, as a rule, the slower films are the more contrasty and also have the finer grain.

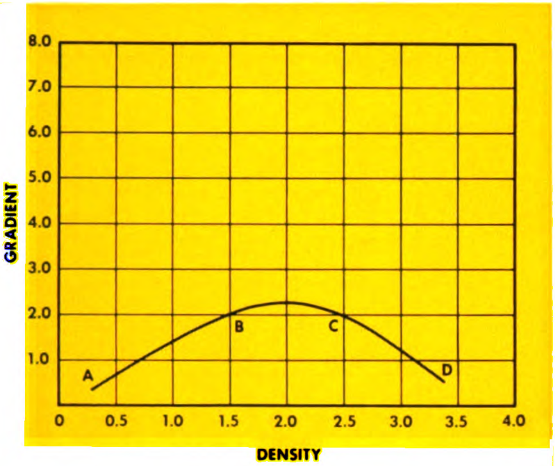


Fig. 78—Gradient vs. density curve of *Kodak Industrial X-ray Film, Type F,* exposed to direct x-rays.

Figure 77 shows the characteristic curve and Figure 78 the gradient curve of *Type F Film,* for direct x-ray exposure. This film is designed for use with calcium tungstate intensifying screens, but is useful under some circumstances for direct x-ray exposures. The characteristic curve shows a gradually increasing gradient in the range *AB*, then becomes almost straight (with nearly constant gradient) for a short distance (*BC*) and thereafter the curve bends to the right (diminishing gradient) and approaches a maximum density of about 3.6, where the gradient is zero. The relation between the characteristic curve and the gradient curve in the various regions is clearly shown. With such a film densities above 3.2 should not be used, since the contrast and differentiation of detail diminish rapidly above this point.

The direct x-ray characteristic curves of the various types of Kodak films used in industrial radiography are shown in Figure 79. It will be noted that the *Type M* and the *No-Screen Films* are similar to *Type A*, in that gradient increases steadily up to the highest densities observed. With *Type K Film*, the characteristic curve becomes straight at a density of about 2.0 to 2.5 and, beyond this, the gradient is constant. These facts are indicated more clearly in the corresponding gradient curves of Figure 80. If the curves of *Types A*, *K*, *M*, and *No-Screen Films* could be carried to higher densities, they would doubtless show a form similar to that of *Type F*.

In Figure 79, it will be noted that the different curves occupy different positions along the log exposure scale. This arises from the differences in film speed, the curves for the faster films lying to the left of those of the slower films, in the region of lesser exposures. From these curves, the relative exposures can be derived to produce a fixed density on the different films. Relative speeds would be inversely proportional to these exposures. A density of 1.5 would be suitable for this computation when

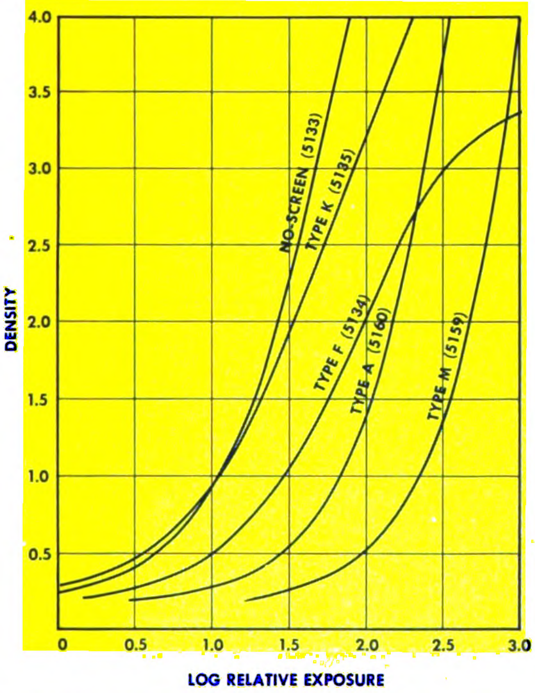


Fig. 79—Characteristic curves of the various *Kodak Industrial X-ray Films* and *Eastman No-Screen X-ray Film.*

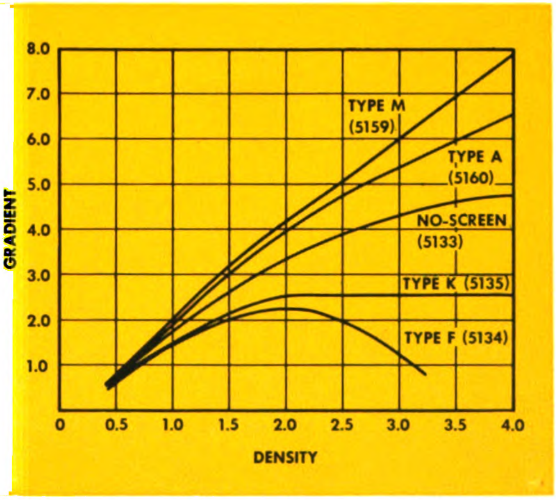


Fig. 80—Gradient vs. density curves for *Kodak Industrial X-ray Films* and *Eastman No-Screen X-ray Film* exposed to direct x-rays.

the radiographs are to be viewed by normal illumination, whereas, 2.5 would serve in the case of high-intensity illumination. These density values would represent the average radiographic density appropriate to the two types of illumination. Relative exposures and speed values derived from Figure 79 are recorded in Table I, at the top of page 89.

Figure 81 shows the characteristic curve and Figure 82 the gradient curve of *Type F Film* exposed with double intensifying screens. The general form of the characteristic curve is similar to that for direct x-rays, with the exception that the gradient increases more rapidly in the low exposure region, and reaches a higher value than with direct x-ray exposures. In other words, this film has a higher contrast with calcium tungstate intensifying screens than with direct x-rays.

It is advantageous to express the contrast property of a film by a single number. This may be done by specifying the average gradient over the useful density range. With high-intensity illumination, the useful density range may be taken as 1.0 to 4.0. A *straight line* drawn between the two selected densities on the characteristic curve has the same gradient as the average gradient of the *curve* over the same density range (Figure 83). Table II records the average gradients of various x-ray films, both for the density range 1.0 to 4.0, and the range 0.5 to 2.5. Since *Type F Film* does not reach a density

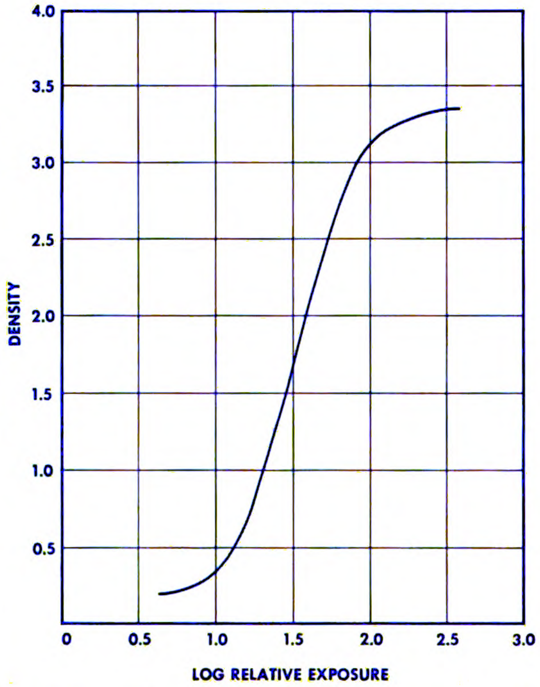


Fig. 81—Characteristic curve of *Kodak Industrial X-ray Film, Type F,* exposed with double calcium tungstate intensifying screens.

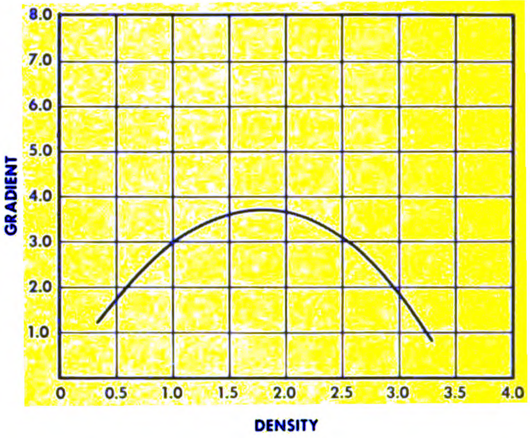


Fig. 82—Gradient vs. density curve for *Kodak Industrial X-ray Film, Type F,* exposed with double calcium tungstate intensifying screens.

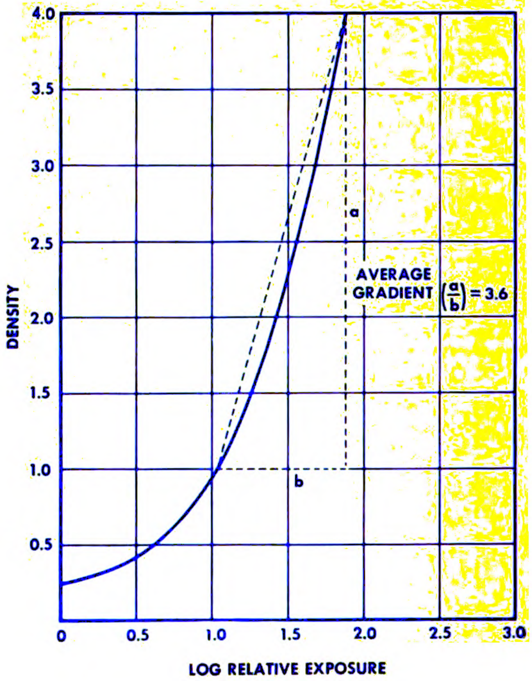


Fig. 83—Characteristic curve of *Eastman No-Screen X-ray Film.* A straight line drawn between two selected densities on the curve has the same gradient as the average gradient of the curve over the same density range.

TABLE I—RELATIVE SPEEDS AND EXPOSURE VALUES DERIVED FROM FIGURE 79

Film	Density = 1.5		Density = 2.5	
	Relative Speed	Rel. Exposure to give D = 1.5	Relative Speed	Rel. Exposure to give D = 2.5
Type M	30	20	30	17
Type A	100	6	100	5
Type F	200	3	120	4.2
Type K	530	1.1	350	1.4
No-Screen	600	1.0	500	1.0

of 4.0, its gradient for the higher density range is given for densities from 1.0 to 3.2.

With x-rays generated at voltages up to 200 KvP, the form and gradient properties of the characteristic curve are not much affected by the wave length or spectral quality of the x-rays. Tests on various types of industrial x-ray films, with radiations ranging from lightly filtered 40-kilovolt radiation to heavily filtered 200-kilovolt radiation, showed only a small change in the characteristic curve, the higher voltages tending to give a slightly lower gradient, or contrast. Reliable characteristic curves for gamma rays and million-volt x-rays are more difficult to obtain and will require further investigation.

The influence of kilovoltage on contrast in the radiograph, therefore, is due primarily to its effect upon the x-ray image, and only slightly to any change in the contrast characteristics of the film. Radiographic contrast may also be modified by choice of a film of different contrast, or by use of a different density range with the same film. Contrast can also be affected by the degree of development, but, in industrial radiography, it is customary to develop films to their maximum, or nearly their maximum, contrast. In the early stages of development, both density and contrast increase quite rapidly with time of development, but at 5 minutes in fresh *Kodak Rapid X-ray Developer* at 68° F., most of the available density and contrast have been reached. With the direct x-ray film types, approximately 30 per cent more speed, and slightly more contrast, can be gained by developing for 8 minutes.

To secure the higher contrast associated with the higher film densities, a greater exposure is required. If it is not feasible to increase the milliamperage or exposure time sufficiently to accomplish the desired result, a suitable increase in kilovoltage will serve almost as well. With films of the direct x-ray type, the loss in subject contrast at the higher kilovoltage is more than offset by the gain in film contrast obtained at the higher density. To demonstrate this point in a particular case, a step tablet of 24ST

TABLE II—AVERAGE GRADIENTS OF INDUSTRIAL X-RAY FILMS EXPOSED TO DIRECT X-RAYS

Film	Gradient	
	Density Range 0.5—2.5	Density Range 1.0—4.0
Type M	2.5	4.6
Type A	2.4	4.3
Type F	1.6	1.8*
Type K	1.7	2.4
No-Screen	2.2	3.6

*Since Type F does not reach a density of 4.0, its gradient for the higher density range is given for densities from 1.0 to 3.2.

aluminum was radiographed on *Type A Film* at a series of voltages, with fixed milliamperage, exposure time, and target-film distance. The films were all given standard development, and measurements of the densities were made of the various steps in the radiographs. These measurements showed that the use of higher kilovoltages, to bring the exposure into the region of higher film gradients, resulted in a marked increase in radiographic contrast. This conclusion is demonstrated in the table below, where the density difference, $D_B - D_A$, between the shadow of a 0.96-inch thickness and that of a 1.52-inch thickness of the aluminum, is recorded for each of the various kilovoltages.

Kv	D_B (0.96" Al)	D_A (1.52" Al)	Radiographic Contrast $= D_B - D_A$	Relative Radiographic Contrast
75	0.58	0.26	0.32	17
100	1.23	0.49	0.74	40
125	2.36	1.01	1.35	73
150	3.87	2.01	1.86	100

By ordinary standards, the 100-kilovolt radiograph in this case would represent about the minimum acceptable density. By raising the voltage to 150 kilovolts, with no other change in the technic, the contrast in the radiograph is increased 2½ times.

It has been shown how the contrast characteristic of a film can be expressed numerically in terms of the average gradient of the characteristic curve over a selected density range. Radiographs may be spoken of as "contrasty," or "flat" (lacking in contrast), but there is no quantitative way of expressing the contrast of a radiograph as a whole. The contrast between two portions of a radiograph, however, can be specified by the difference between their densities, or $D_B - D_A$ for areas *A* and *B*, as exemplified in the table above. The contrast between two parts of an x-ray image may be expressed by the ratio of the corresponding x-ray intensities.

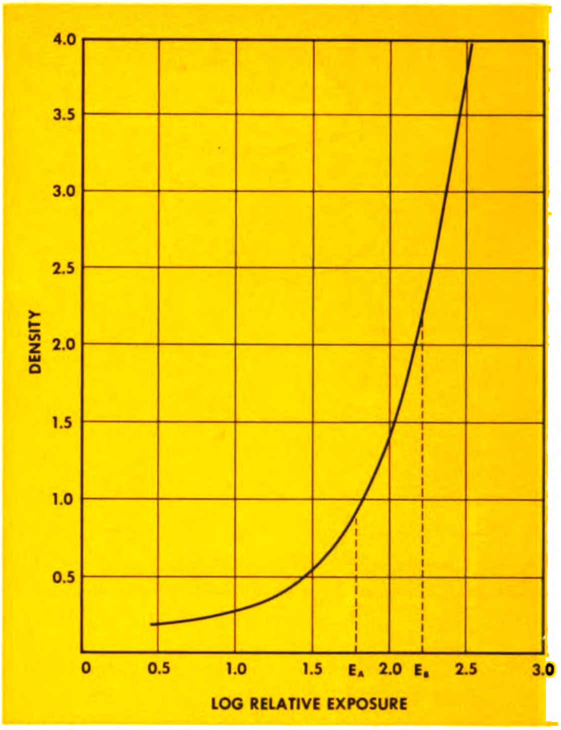


Fig. 84—Characteristic curve of *Kodak Industrial X-ray Film, Type A*. E_A and E_B represent the log relative exposures in two areas of a radiograph.

Radiographic contrast is the resultant of the combination of subject contrast and film contrast. In the log E scale of the graph of Figure 84, let the points E_A and E_B represent the exposures arising from two areas, *A* and *B* of the x-ray image, for a suitable exposure time, t. The x-ray intensities in these two areas are I_A and I_B, respectively, so that $E_A = I_A t$ and $E_B = I_B t$. The corresponding subject contrast is $\frac{I_B}{I_A}$.

$$\log \frac{I_B}{I_A} = \log \frac{E_B}{E_A} = \log E_B - \log E_A.$$

If the average film gradient over this log E interval is $\bar{G}_{AB}$, then $D_B - D_A = \bar{G}_{AB} (\log E_B - \log E_A)$, or the contrast in the radiograph is equal to the logarithm of the subject contrast multiplied by the film contrast. Thus, a given radiographic contrast can be secured by a combination of a high film contrast and a low subject contrast, or vice versa, as long as the product of film contrast and logarithm of the subject contrast remains the same.

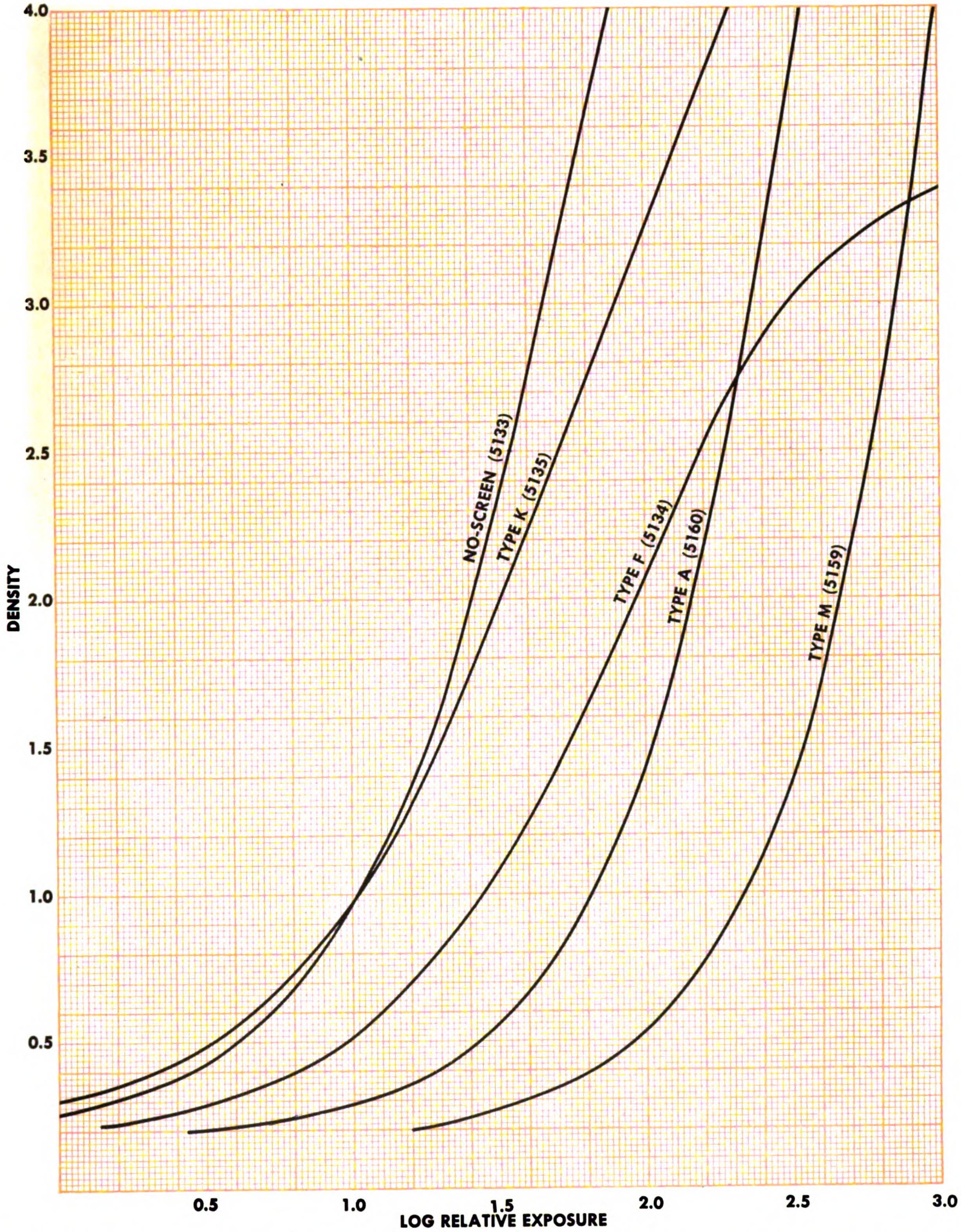


Fig. 85—Characteristic curves of Kodak films used in industrial radiography, for direct or lead foil screen x-ray exposures in the voltage range of 50 to 200 kilovolts. The curve of *Eastman Blue Brand X-ray Film* is similar in form to the corresponding curve of *Type F Film.*

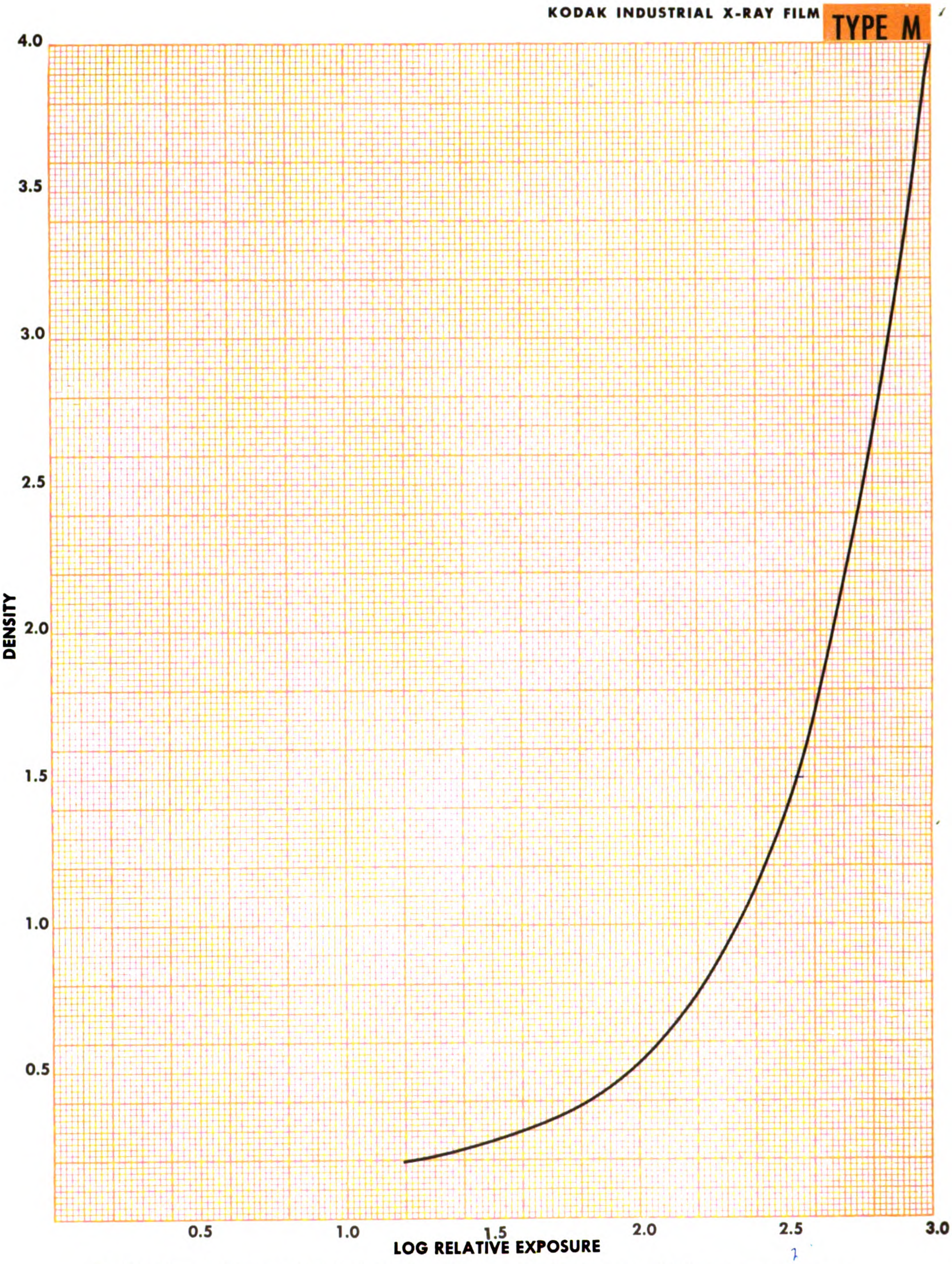


Fig. 86—Characteristic curve, *Kodak Industrial X-ray Film, Type M,* with direct or lead foil screen x-ray exposure.

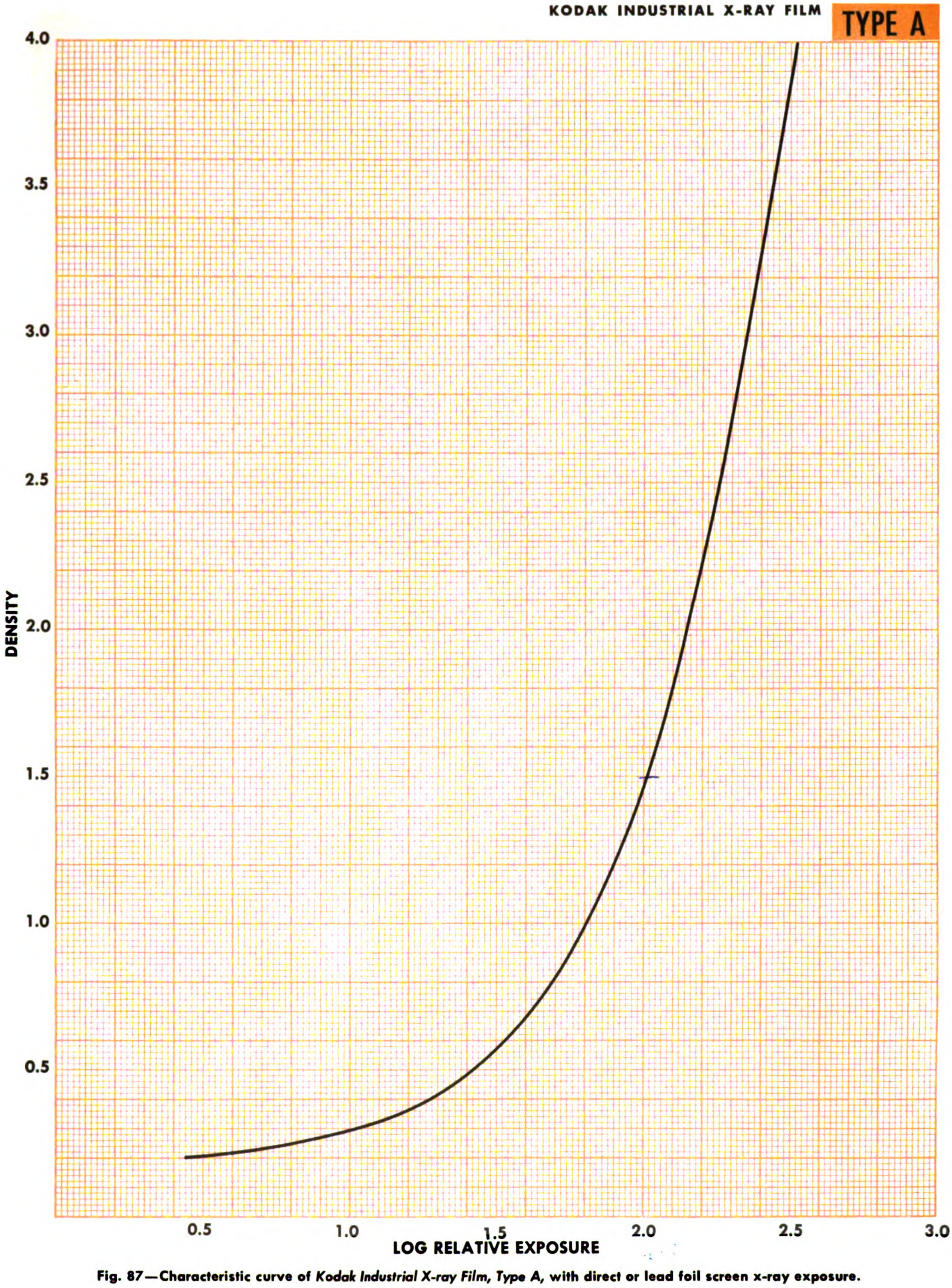


Fig. 87—Characteristic curve of *Kodak Industrial X-ray Film, Type A,* with direct or lead foil screen x-ray exposure.

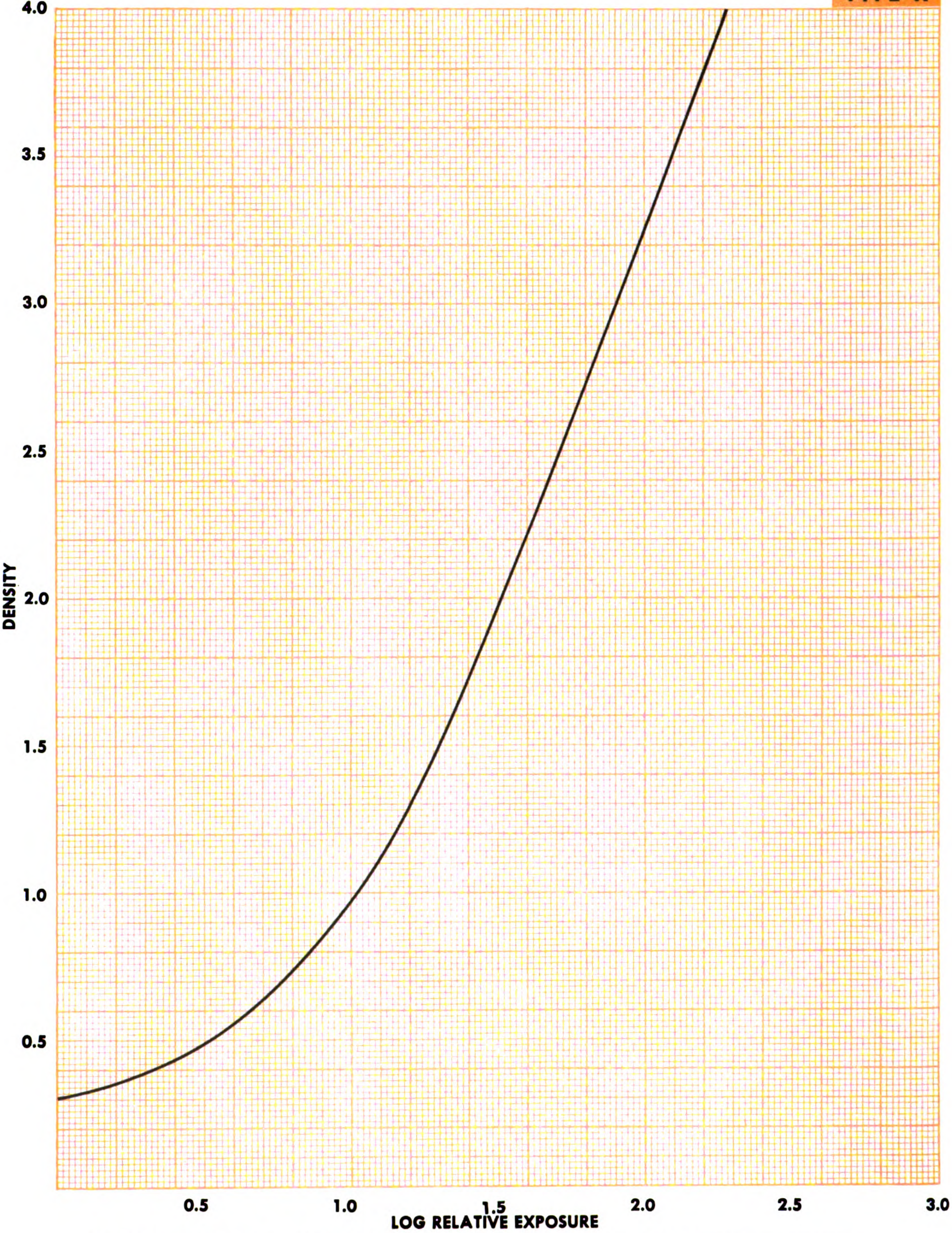


Fig. 88—Characteristic curve of *Kodak Industrial X-ray Film, Type K,* with direct or lead foil screen x-ray exposure.

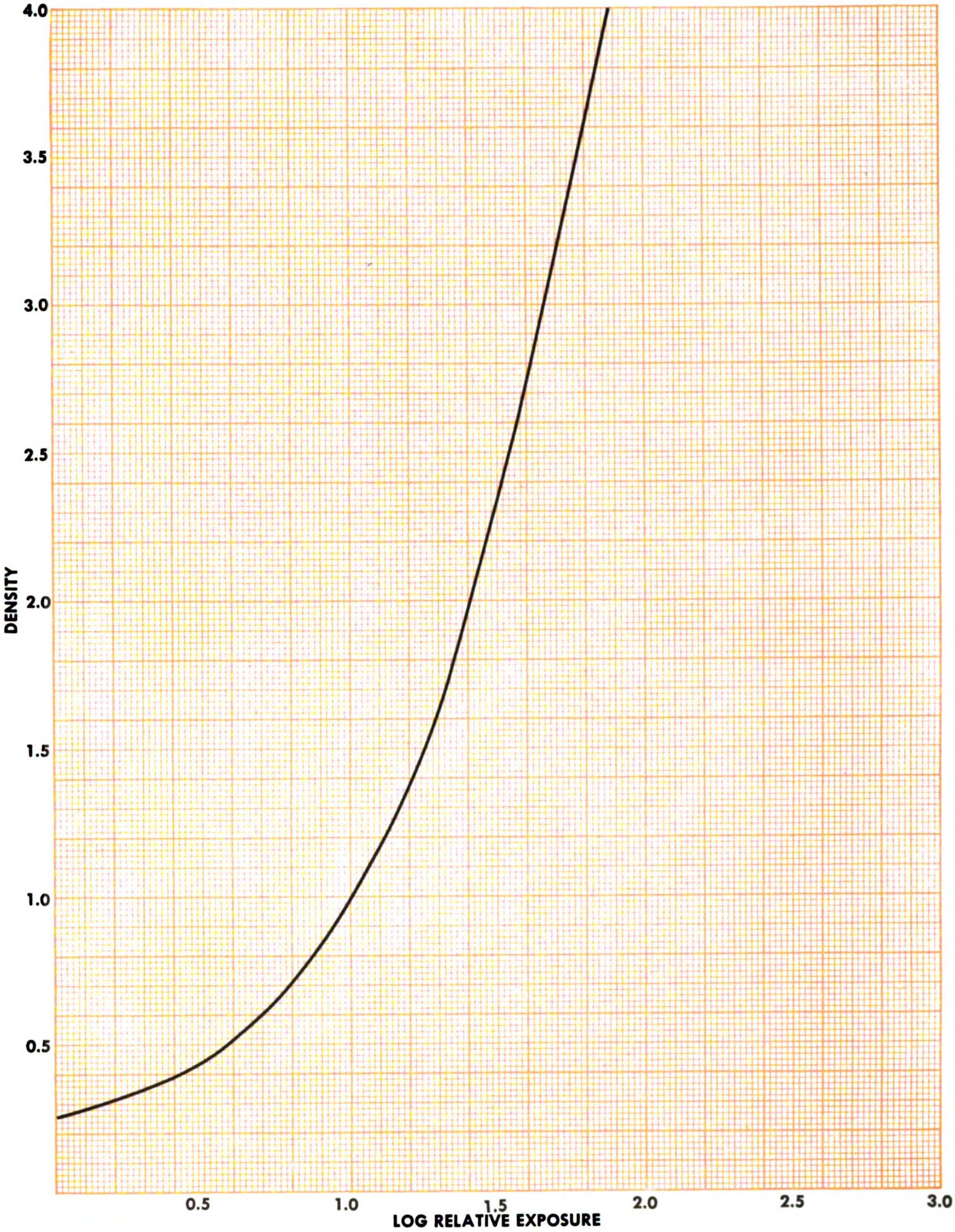


Fig. 89—Characteristic curve of *Eastman No-Screen X-ray Film*, with direct or lead foil screen x-ray exposure.

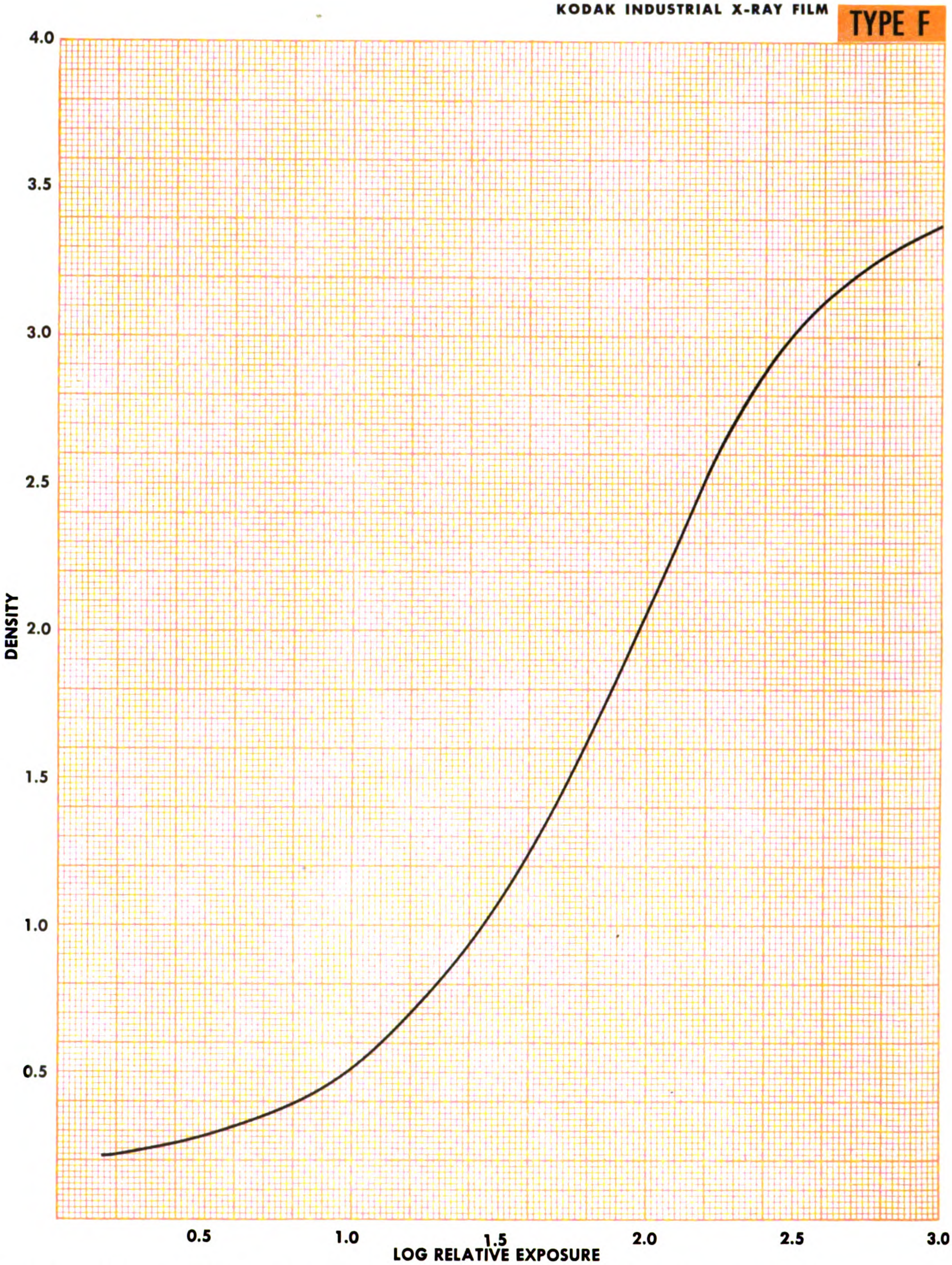


Fig. 90—Characteristic curve of *Kodak Industrial X-ray Film, Type F,* and *Eastman Blue Brand X-ray Film,* with direct or lead foil screen x-ray exposure.

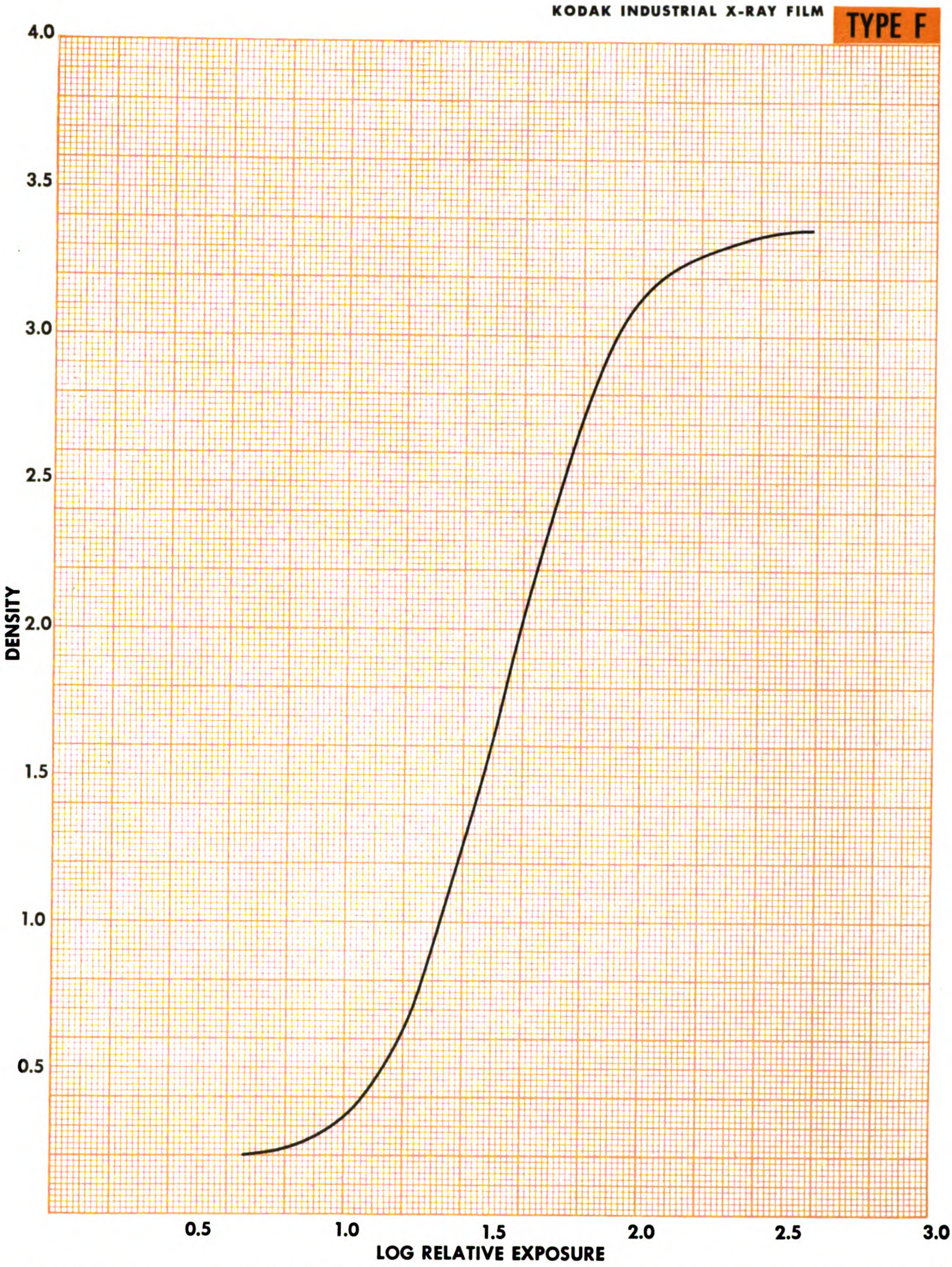
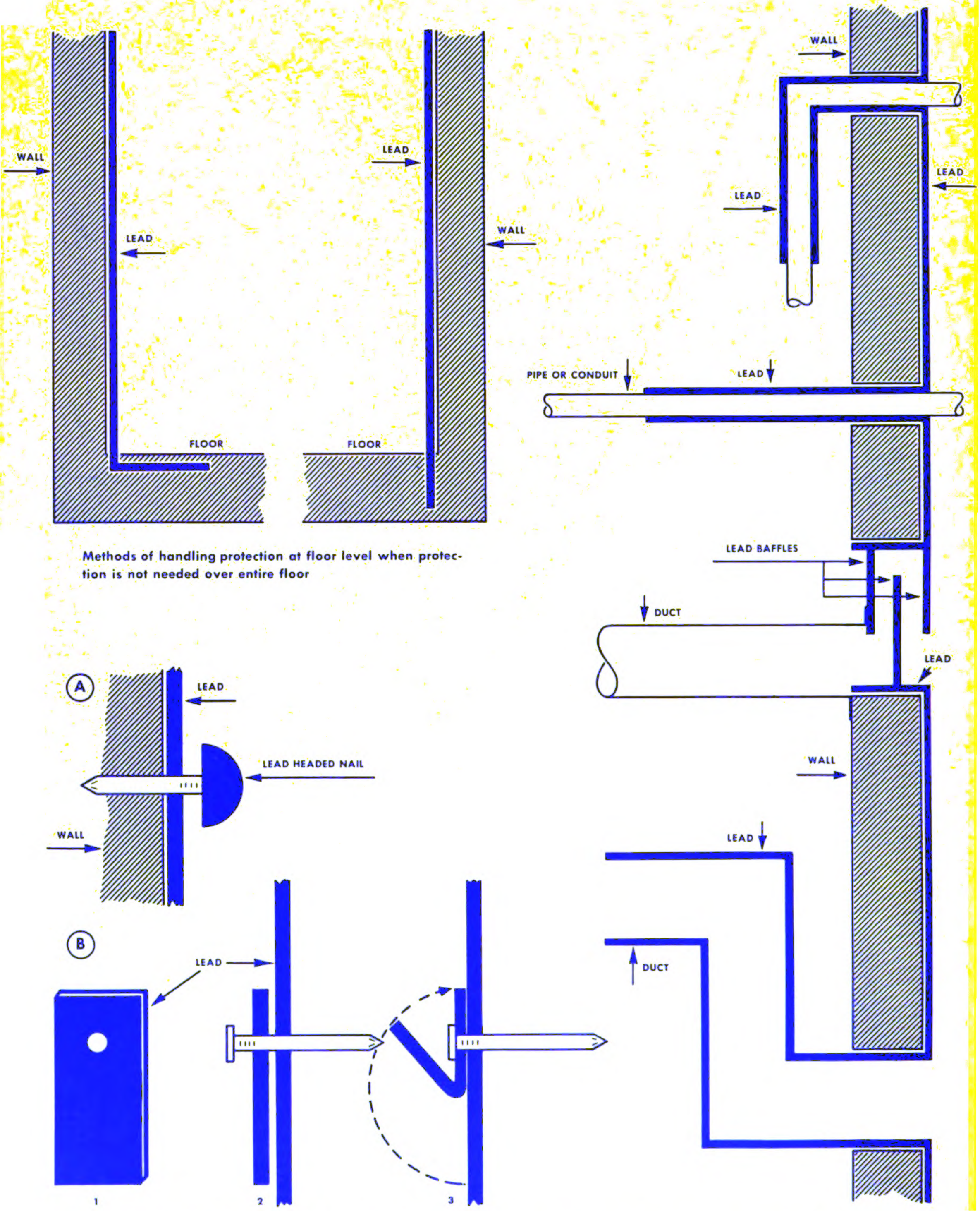


Fig. 91—Characteristic curve of *Kodak Industrial X-ray Film, Type F*, exposed with double calcium tungstate intensifying screens. The curve of *Eastman Blue Brand X-ray Film* is of the same form, but shows somewhat slower speed.



Methods of handling protection at floor level when protection is not needed over entire floor

Methods of sealing nail or screw holes in lead protection
A—Lead-headed nail
B—Lead strip folded over nail head

Methods of shielding when pipes, ducts, or conduits must pass through the walls of an x-ray room.

Figure 92

APPENDIX II

PROTECTION

One of the most important considerations in the x-ray or gamma ray laboratory is the provision and exercise of adequate safeguards for the personnel. The general principles of the necessary protective precautions are discussed in the following text. In addition, the *Safety Code for the Industrial Use of X-rays* proposed by the American Standards Association, 70 E. 45th St., New York 17, N. Y. (price $1.50), should be obtained and carefully studied. New installations should be constructed in compliance with the provisions of this code, and existing installations should be checked to make certain that they meet with the requirements.

Any of the body tissues may be injured by overexposure to x-rays or gamma rays—the blood, skin, and some internal organs being particularly sensitive. For this reason, persons who are exposed regularly to small quantities of x-rays or gamma rays should have periodic blood counts and physical examinations, under the direction of a physician, in order to note at the earliest possible moment any effects which might be attributed to these exposures.

Unless exposure to x-rays or gamma rays is kept at a minimum, the cumulative effect may cause injury to the body, and it is essential that workers in the x-ray department be adequately protected against radiation at all times. Furthermore, protective measures should be so arranged that those in departments near the places where x-rays or radium are used are also safe. Precautions should be particularly observed when radiography must be done in the shop rather than in a specially protected radiographic department.

The unit of x-ray and gamma ray quantity used when dealing with the effects of these radiations on living organisms is known as the *roentgen*. This unit is based upon the effect of x-rays in ionizing air, i.e., in making it electrically conducting.* X- or gamma ray quantity, in terms of roentgens, is measured by means of an instrument called an "r-meter," which measures the conductivity of air produced by the x-ray beam in question.

The daily tolerance dose of x-rays or gamma rays is that which, over a period of years, will produce no damage to the human body. The accepted value at present is 0.1 roentgen per day. This value of the tolerance dose will be used throughout this chapter.

PROTECTION AGAINST X-RAYS

It is essential that the operator, and any other personnel in the vicinity, be protected at all times against dangerous amounts of radiation. Exposure may be due to the direct beam from the x-ray tube target or to scattered radiation arising from objects in the direct beam. Therefore, while the exposure is being made, the operator should always be protected by sufficient lead, or its equivalent, shielding him from the x-ray tube, the part being radiographed, and any other matter exposed to the x-rays. This protection may be provided in a number of ways, depending upon the x-ray installation and the use to which it is to be put. Whenever possible, protective measures should be built in as permanent features of the installation. Preferably, the x-ray generator and the work should be enclosed in a room or cabinet, with the necessary protection incorporated in the walls.

The commonest method is to locate the x-ray tube

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*The *roentgen* is the quantity of x- or gamma radiation such that the associated corpuscular radiation per 0.001293 gram of air produces, in air, ions carrying 1 esu of quantity of electricity of either sign. (International Committee for Radiological Units, 1937.)

within a room completely lined with lead of a sufficient thickness to provide adequate protection. All the x-ray machine controls are located outside the room.

In some cases where large numbers of relatively small parts are inspected, the protection may be in a more compact form. This consists of a mechanically operated, lead-lined hood. The hood is lowered over the x-ray tube, the specimens, and the cassette, thereby completely enclosing them for the duration of the exposure. When the exposure is completed, the hood is raised to allow the removal of the radiographed parts and the placement of a new batch. The electrical controls are interlocked so that the x-rays cannot be turned on until the hood is in the closed position.

In placing of equipment and design of protective enclosures, certain principles must be kept in mind. Careful application of these principles adds to the safety of the personnel, and may decrease cost.

Both safety and economy will be promoted if the amount of radiation which must be absorbed in the outside wall of the enclosure is kept to a minimum. To this end, the distance from the x-ray tube target to any occupied space should be kept as great as possible. Further, if the nature of the work permits, the direct beam should never be pointed toward these occupied areas, and the angulation of the tube should be restricted to a minimum.

Ideally, the lead housing around the x-ray tube should give protection against all primary radiation except the useful beam, although this is not always feasible in practice. The useful beam itself should be limited in cross section by the use of cones or diaphragms.

If there are parts of the x-ray room which, because of the design of the equipment, can never be exposed to direct radiation, certain economies in the installation of protective material are possible. Since the intensity is much lower, less protection is necessary against scattered radiation alone. When advantage is taken of these economies, great care must be exercised in rearranging equipment, lest it be possible to direct the full intensity of the x-ray beam against a wall containing protection against the scattered radiation *only*.

The protective material, usually lead, in the walls of the enclosure, whether it be room or cabinet, must be of sufficient thickness to reduce the exposure in all continuously-occupied areas to less than 0.1 r per day. The American Standards Association code previously mentioned (see p. 99) contains charts and tables for the computation of the necessary lead thicknesses for protection against both direct and scattered radiation.

In some cases it may be possible for the personnel of an x-ray department, or other employees, to be exposed to radiation from more than one x-ray machine. In such cases, the amount of protection must be increased to a point where the *total* exposure in any occupied area is under 0.1 r per day.

Where the work is too large or heavy to be brought to the x-ray machine and hence the radiographic testing must be done in the open shop, special precautions are necessary. These include a completely lead lined booth large enough to accommodate the x-ray machine controls, the operator, and other x-ray workers. The booth may be completely enclosed, or open on one side. In any event, the exposure within it should be less than 0.1 r per day. Lead cones on the x-ray machine should be used to confine the x-ray beam to a certain direction and to the minimum angle that can be used. Portable screens should be provided to protect workers near-by. Guard rails or ropes and warnings should be used to keep plant personnel at a safe distance.

MATERIALS AND CONSTRUCTION FOR PROTECTION AGAINST X-RAYS

Lead is the most common material used to provide protection against x-rays. It combines high protective efficiency with low cost and easy availability. In most cases, recommendations on protective measures are given in terms of lead thickness.

When using lead for protection, care must be taken to avoid any leaks in the shielding. This means that adjacent lead sheets should be overlapped, not merely butted, even if the sheets are to be burned together throughout the whole length of the joint. The heads of any nails or screws which pass through the lead should be carefully covered with lead.

Extra precautions should be taken at those points where water pipes, electrical conduits or ventilating ducts pass through the walls of the x-ray room. For small conduits and pipes, it is usually sufficient to provide a lead sheathing around the pipe for some distance on one side of the lead protective barrier in the wall. This sheath should be continuous and very carefully joined, by a burned joint, to the lead in the wall. Better protection is afforded by having a right-angled bend in the pipe either inside or outside the x-ray room. The pipe is then covered with a lead sheath. This should be carefully joined to the lead in the wall and should cover the pipe or duct to a point well beyond the right-angled bend. In the case of a large opening for ventilation, lead baffles arranged as in Figure 92, page 98, will serve as a stop for x-rays, while permitting the passage of air. When a large ventilating duct is brought into the x-ray room, two right-angled bends covered with lead will serve to prevent the escape of x-rays.

It may be necessary to put up x-ray films against the outside of the wall in questionable areas, and to direct the full intensity of the x-ray beam against the area, in order to test the protection.

If the x-ray room is on the lowest floor of a building, the floor of the room need not be completely protected. The lead protection in the walls should not stop at the floor level, however. An "apron" of lead, continuous with the protection within the wall, should be placed in the floor, extending inward from all four walls (see Figure 92). The purpose of this apron is to prevent x-rays from escaping from the room by penetrating the floor and then scattering upward outside the protective barrier. An alternative is to extend the lead protection in the walls downward for some distance below the floor level (see Figure 92). The same considerations apply to the ceiling if the x-ray room is located on the top floor of a building. Of course if there is occupied space above or below the x-ray room, the ceiling or floor of the x-ray room must have full radiation protection over its whole area.

Although lead is the most efficient material for x-ray protection, other materials find some application. In particular, concrete or brick walls required structurally may afford considerable x-ray protection, and may reduce the thickness, and hence the cost, of the lead required.

It is at voltages above 400 KvP that concrete is most used as a protective material. The lead thicknesses required at these potentials are so great that fastening them to the walls becomes a serious problem, and concrete is used because of the ease of construction. The *ASA Safety Code for the Industrial Use of X-rays* contains data on the protective values of various constructional materials.

PROTECTION AGAINST GAMMA RAYS

The gamma rays from radium or other radioactive materials have biological reactions similar to those produced by x-rays. It is necessary, therefore, that the personnel conducting gamma ray work be informed of the precautions used to insure safety.

Gamma rays are very penetrating; 1.3 cm. of lead reduces the intensity of gamma rays from radium only about 50 per cent. This makes the problems of protection somewhat different from those encountered in x-ray protection. In general it is not feasible to provide safety from gamma rays solely by means of a protective barrier. A combination of distance and protective material, or distance alone, is usually required. The previously mentioned code of the American Standards Association contains a section on gamma ray protection whose provisions should be rigorously followed.

When the radium is not in use, protection may be obtained by keeping it in a thick lead container, since in this case the total amount of lead needed is not great. If it is not desirable to use the amount of lead required for full protection, the thick lead container may itself be kept in a wooden box of such dimensions that the gamma ray intensity at the outer surface of the box is less than 0.1 r per day.

In cases where the radium is used in only one place in the plant, it may be stored in a narrow well in the earth at least six feet deep directly beneath the spot it occupies during an exposure. The radium remains in the well when not in use and while specimens and film holders are being put in place or removed. When it is desired to start an exposure, the radium may be raised to the desired position by a simple pulley system operated from a safe distance, preferably near the exit.

If it is necessary to transport the radium about the plant, a small truck carrying a thick-walled lead box should be provided. The lead thickness should be at least equal to that of the appropriate shipping container (see page 102), and should have a rigid handle which will keep the radium a safe distance from the body. The length of handle required will depend, of course, upon the lead thickness and amount of radium. The carrying case or truck should be so constructed that it is impossible, or at least inconvenient, to pick it up or pull it other than by the handle.

In transferring radium to or from the storage container, truck, or exposure position, it should never be handled directly, but always by strings or tongs at least one foot long. If the container housing the radium is magnetic, it may be handled by means of a small electromagnet, powered by dry cells, on the end of a long rod.

Since the thicknesses of protective materials required for adequate shielding from gamma rays are so great, the most economical method of protection while the radium is in use is by distance. A danger zone should be roped off around the location of the radium capsule and personnel should be forbidden to enter this zone except to put the radium in position or return it to its safe. Suitable conspicuous signs should be provided to warn off the casual passers-by. Tables and charts in the *ASA Safety Code for the Industrial Use of X-rays* give data for calculating the distances from various amounts of radium at which a radiation hazard exists. It must be kept in mind that at large distances (over 6 feet) from the radium the presence of a large mass of scattering material, e.g., a wall, will materially increase the gamma ray dose. This increase may be as much as 50% of the dose as calculated without the presence of scattering material. Thus, to insure that protection is adequate, factors other than distance must be kept in mind when considering protection from gamma rays.

Precautions must be taken in shipping radium not only to protect those who will handle it in transit, but also to prevent the fogging of photographic materials which may be transported in the same vehicle. The Railway Express Agency has prepared a table, below, to guide in the construction of shipping containers for radium. During shipment, the radium is kept at least ten feet from any package labeled as photographically sensitive material, and at least 15 feet from any package identified as x-ray film.

A danger, rarer than the radiation hazard, in the handling of radium lies in the possibility of the inhalation of radon gas by the personnel. Radon is a radioactive product of radium disintegration. The radium is sealed in a gas-tight container by the producer, in order to prevent radon leakage. Occasionally, however, the container may spring a leak as a result of mishandling, and allow the radon to escape to the atmosphere where it may be inhaled. It is suggested that all radium capsules be tested for leakage, and that thereafter any capsule that has received physical damage be again tested. A sudden

TABLE I—RADIUM SHIPPING PROTECTION

Railway Express Agency Chart showing Lead Thicknesses for Radium shipping containers, and allowable times in transit

Quantity of Radium Milligrams	Lead Thickness — Inches ¼	½	1	1½	2	2½	3	3½	4
	Allowable Hours in Transit								
Under 15 mg	40	60	110						
15 mg and under 25	20	30	55	110					
25 mg and under 35	14	20	36	73	146				
35 mg and under 45	10	15	28	55	110				
45 mg and under 55	8	12	22	44	88	170			
55 mg and under 65		10	18	36	73	142			
65 mg and under 75		8	16	31	63	122			
75 mg and under 85			14	27	55	106			
85 mg and under 95			12	24	48	95			
95 mg to 100 incl.			11	22	44	85	170		
200				11	22	43	86	172	
300				8	14	28	56	112	
400					11	22	44	88	172
500					8	17	34	68	136
600					7	14	28	56	112

drop in the gamma-ray emission of a radium capsule is suggestive of radon leakage, and such a capsule should be tested immediately.

MEASUREMENT OF RADIATION RECEIVED BY PERSONNEL

The amount of radiation received by an individual in the vicinity of x-ray apparatus may be recorded by a "fountain pen" type of ionization chamber. For use, it is first charged electrically by a special device. It is then carried in the pocket for one or more days, and returned to the charging unit for observing the amount of discharge expressed in roentgens. Sometimes such a chamber develops electrical leakage over its insulation so that it will register a substantial discharge without exposure to x-rays or gamma rays. Trouble from this source may be minimized if the chamber is kept in a container while being carried by an operator. The container should give protection against moisture, dust, and mechanical damage, and should be made of a material transparent to x-rays. The chamber should be checked frequently to make sure that its scale reading, without exposure, is relatively small for a period equal to that to be used for the stray radiation test.

Photographic films may also be used to estimate exposures received by personnel in the vicinity of x-ray or gamma ray sources. Photographic films were not designed for such a purpose, but by employment of the proper procedure, films may be used to indicate when unsafe dosages are being received.

By themselves, films are not suitable for the measurement of radiation, since their response may be affected by a variety of factors, such as the temperature, humidity, age, and storage conditions of the films, and also by the degree to which the films are developed. Films may be used fairly reliably for the *comparison* of quantities of radiation, however, and the essential feature of the method is to expose some films (to be called "calibration films") to a known quantity of radiation, and to process these with similar films (to be called "test films") carried by personnel. By comparing the resulting densities, it is possible to determine whether the test films have received appreciably more radiation than the calibration films.

For example, suppose that test films are to be carried for 5 days by personnel exposed to scattered x-rays produced by 200 kilovolt primary x-rays. Calibration films, say, two or more, of the same emulsion number, should be exposed for 5 x 0.1 roentgen, or 0.5 roentgen, of 200 kv primary x-rays, and processed with the test films. If the density of the test films exceeds that of the calibration films, the existing protective measures should be investigated and the necessary remedial action taken.

One drawback of the photographic method is that wide differences may occur in the number of roentgens required to affect the film, depending on the quality of the radiation. For example, the change from 200 kv x-rays to 1000 kv x-rays greatly increases the number of roentgens necessary to produce a given photographic density. Little or no difference in this respect is observed between gamma rays and million volt x-rays. Lightly filtered x-rays generated at 60 kv to 200 kv show about the same relation between roentgens and photographic effect. If such x-rays are heavily filtered, however, the number of roentgens required to affect the film increases considerably, and the influence of tube voltage becomes more pronounced.

The film method must, therefore, be used with proper consideration of the above facts. For example, if a film is exposed to both gamma rays and 200 kv x-rays, it will not add the two exposures correctly in terms of roentgens. To be on the safe side, the calibration exposures should be made to the hardest radiation to which the test films may be exposed.

In a similar manner, the radiation scattered from a 200 kv x-ray beam and the direct 200 kv x-rays transmitted through a protective barrier will not be evaluated equally by the film.

In general, the principal situation requiring tests of exposures received by personnel is around an open installation, where the provision of completely protective barriers is not feasible. The exposure arises largely from scattered radiation and the calibration film exposures may be made by primary radiation at the highest kilovoltage used in the radiography. If tests of the radiation transmitted through a protective barrier are to be made with x-rays generated at 400 kv or less, the calibration exposures should be made with heavily filtered primary radiation, as will be explained more fully. 1000 kv x-rays, or gamma rays, transmitted through a protective barrier, will be evaluated by the film in substantially the same degree as these radiations without special filtration.

TABLE II—FILM MEASUREMENT OF UNFILTERED RADIATION

Roentgens of Unfiltered Radiation Required to Produce D = 1.0 on Various X-ray Films

Film	Radiation	Roentgens for D = 1.0	Days* to Produce D = 1.0
Eastman Radiatized Dental X-ray Film (1 film per packet) (Code DF7 or DF11)	100 kv x-rays	0.5	5
	150 kv x-rays	0.5	5
	200 kv x-rays	0.6	6
Eastman Rapid-Processing Dental X-ray Film (1 film per packet) (Code DF-65 or DF-67)	400 kv x-rays	0.4	4
Kodak Industrial X-ray Film, Type M (Code 5159) Single film in opaque paper wrapping	100 kv x-rays	0.4	4
	150 kv x-rays	0.4	4
	200 kv x-rays	0.5	5
Eastman Super-Speed Occlusal Dental X-ray Film (2 films per packet) (Code DF45)	1000 kv x-rays	0.7 (front film)	7
		0.5 (back film)	5
	gamma rays	0.7 (front film)	7
		0.6 (back film)	6
Eastman Blue Brand X-ray Film (Code 5121) or Kodak Industrial X-ray Film, Type F (Code 5134). Single film in opaque paper wrapping	1000 kv x-rays	0.9	9
	gamma rays	0.9	9
Kodak Industrial X-ray Film, Type K (Code 5135). Single film in opaque paper wrapping	1000 kv x-rays	0.4	4
	gamma rays	0.5	5

All development—5 minutes in Kodak Rapid X-ray Developer at 68°F.

*Assuming an average daily exposure of the human tolerance dose (0.1 roentgen).

Since scattered radiation is softer than primary radiation, it may be overvalued, more or less, by films calibrated with primary radiation. This effect is probably small for gamma rays and for x-rays up to 200 kv, while it may be quite large with 400 kv and 1000 kv x-rays. In any case, the error in film response is in the direction of increased safety.

The selection of film types for recording radiation received by personnel was based on the assumption that a suitable density, say 1.0, should be produced by approximately five days exposure to the tolerance dose of 0.1 roentgen per day. Such a period would average the exposure over a reasonable time, and yet would not delay the results of the test too long.

Dental x-ray films are manufactured in a wide variety of speeds and, as supplied in light-proof packets, are especially convenient for the purpose. Some industrial types of x-ray film are also included in case the appropriate dental films are not available; these must be cut to suitable size and enclosed in a light-proof wrapping.

In Table II are listed the various types of x-ray films, the number of roentgens needed to produce a density of 1.0, and the approximate number of days each must be carried to produce a density of 1.0 when the average exposure per day is the tolerance dose of 0.1 roentgen. These values are given for gamma rays and for primary x-rays generated at several selected voltages. All films are to be developed for 5 minutes in fresh *Kodak Rapid X-ray Developer* at 68°F., with occasional agitation.

Films are worn on the chest. In the case of dental packets, the "tube side" should be away from the body. An extra wrapping or envelope of heavy paper, or preferably some thin moisture-proof material transparent to x-rays will help protect the film against dust, moisture, and mechanical damage during the time it is being carried.

If ionization equipment is available, it is recommended that separate films, say two or more, of the same emulsion number and preferably from the same package as the test films, be exposed to a known dose, in roentgens, of the primary radiation used in the radiography. The dose should be 0.1 roentgen multiplied by the number of days the test films are carried. Thus, if the test films are carried for six days, the calibration films should receive an exposure of 0.6 roentgens. These films should be processed with the test films carried by the personnel. If the test films show greater density than the separately exposed calibration films, it indicates that the test films have received more than an average of 0.1 roentgen per day. Usable densities will be obtained on test films carried for periods ranging from about one half to about three times the periods given in column 4 of Table II (page 104).

This procedure involving the use of calibration films should be followed if at all feasible, as it lessens considerably the influence of film and processing variations, and thereby greatly increases the reliability of the film method of monitoring stray radiation.

If ionization equipment is not available for measuring the exposures of calibration films, the use of test films alone will give some indication of degree of safety if the entire procedure is performed with the utmost care. It is essential that the films used be in good condition and not unduly fogged by reason of age, improper storage conditions or the like. The recommended development procedure (see page 104) should be faithfully carried out in every detail. The results of such tests could easily be in error by a factor of 3 due to cumulative errors from various sources. Hence the test films should be carried for a period which is three times the number of working days given in column 4 of Table II. If, after processing, the test films show a density greater than 1.0, protective measures should be investigated to determine whether or not they are adequate.

If no densitometer or calibrated density strip is available for measuring the density of the exposed and processed films, a very rough estimate of a density of 1.0 can be made. A film having a density of 1.0 when placed on a newspaper will obscure the readability of ordinary newsprint under daylight conditions.

In exposing calibration films to gamma rays, it is simpler to calculate the exposure in roentgens than to measure it. Each milligram of radium emits approximately 0.0008 roentgen per hour at a distance of 1 meter. To absorb secondary beta rays from the air, the calibration film packet should be covered (on the radium side) with a layer of copper or brass ½ millimeter (0.020 inches) thick. As a support during the calibration exposure, the films may be mounted on cardboard, but should not be backed with any considerable amount of other material.

Since beta rays are absorbed in the superficial layers of the body, their effects will not be the same as those of the highly penetrating gamma rays. If it is desired to record both beta and gamma radiation, in order to guard against their combined effects, no filter should be placed over the film packet. If for any reason the beta rays are to be excluded, the film packets carried by the personnel should be covered with a ½ millimeter (0.020 inch) layer of copper or brass.

Where employees are exposed to radiations from several x-ray machines whose maximum kilovoltages are different, the calibration films should be exposed to radiation generated at the highest maximum kilovoltage. This will insure the greatest margin of safety in the protection measurements. If no ionization equipment is available, and film alone is used to evaluate protection, test films should be carried for the time proper for radiation generated at the highest kilovoltage available (see Table II). If there is simultaneous exposure to both x-rays and gamma rays, it should be assumed that the entire exposure is due to gamma rays. The test and calibration films should be those used with gamma rays (see Table II), and the calibration films should be exposed to gamma rays.

In using film to test for exposure to x-rays or gamma rays, an effort should be made to insure that the blackening or density observed is produced largely by the radiation under test and not by some other cause, such as age of the film, poor storage conditions, excessive exposure to safelight illumination, or improper processing conditions. A portion of each test film should be covered, on both sides of the film, with a strip of lead 1/16 inch thick and about ½ inch wide. The appearance of the shadow of the lead marker on the processed film shows that the film has been exposed to a penetrating radiation. For x-rays up to 200 kv, the lead gives adequate protection to the film, when exposures are normal, so that this area of film can be judged for fog arising from sources other than the radiation under test.

Very hard radiations, such as gamma rays and 1000 kv x-rays, will readily penetrate the lead marker, so that its shadow, though it may demonstrate exposure to radiation, does not indicate extraneous film fog. In this case, separate unexposed films should be processed with the test films to test for fog other than that due to the radiation under test. With x-rays generated above 200 kv, a layer of brass or copper about ¼ millimeter (.010 inch) thick should be interposed between the marker and the film to protect the film from secondary radiation from the lead.

A wire paper clip is *not* a satisfactory marker for the film, since its x-ray or gamma ray absorption is too low. Furthermore, if it is too loose it may be accidentally moved during the time the film is carried; if it is too tight it may produce troublesome pressure marks.

Dental x-ray films may also be used to determine approximately the adequacy of the lead protection built into x-ray room walls and the like. In the case of gamma rays and 1000 kv x-rays the values given in Table II should be applicable to the radiation transmitted by protective barriers. With x-rays up to 400 kv, the data of Table II are not valid when these radiations are highly filtered.

Table III gives the number of roentgens to produce a density of 1.0 with heavily filtered radiations (column 3), together with exposure conditions for calibration films (columns 5 and 6). If no ionization equipment is available, film may be used alone. It should be exposed for three times the intervals shown in column 4, to allow a margin of safety for the inherent inaccuracies of this method. Development should be 5 minutes with occasional agitation in fresh *Kodak Rapid X-ray Developer* at 68°F. Films used to test radiation transmitted by a protective barrier should be backed with a suitable thickness of lead in case the films are accessible to radiation from other directions.

Both the ionization and photographic methods of testing the exposures of personnel to radiation must be performed with adequate care to assure the most dependable results, and the findings of either method may be vitiated by unfavorable conditions. Where feasible, it would seem desirable to combine both methods, using one to check the other.

For example, in addition to films or chambers carried by the personnel, both films and chambers could be mounted together in some fixed location exposed to stray radiation, and their responses compared. If safety tests are not carried on continuously, enough repeats should be made to provide ample data for reliable conclusions. Series of tests should also be repeated from time to time to determine whether any change, either in the conduct of the personnel or in the installation, has operated to increase the radiation hazard.

TABLE III—FILM MEASUREMENT OF HEAVILY FILTERED RADIATION

	Roentgens of Heavily Filtered Radiation to Produce D = 1.0				
				Calibration Condition	
Radiation through Protective Barrier	**Film Type**	**Roentgens for D = 1.0**	**Days*** Exposure**	**Lead Filter**	**Roentgens for D = 1.0**
100 kv x-rays	*Ultra-Speed Dental**	0.2	2	0.4 mm	0.15
150 kv x-rays	*Ultra-Speed Dental**	0.3	3	0.8 mm	0.24
200 kv x-rays	*Ultra-Speed Dental**	0.6	6	1.3 mm	0.54
400 kv x-rays	*Super-Speed Occlusal***	0.7 (front film)	7	1.5 mm	0.7
		0.5 (back film)	5	1.5 mm	0.5

**Eastman Ultra-Speed Dental X-ray Film* (1 film per packet) Code DF54 or DF58.
***Eastman Super-Speed Occlusal Dental X-ray Film* (2 films per packet) Code DF45
***Assuming an average daily exposure of the human tolerance dose (0.1 roentgen)
All development—5 minutes in *Kodak Rapid X-ray Developer* at 68°F.

It must be kept in mind that carelessness on the part of the personnel can destroy the value of the most elaborate means of protection against radiation. The periodic tests are just as much a check on their habits as on the actual shielding from the x-rays themselves.

ELECTRICAL SAFEGUARDS

The voltages used to energize radiographic tubes are highly dangerous, and the best assurance of safety against hazard from them is the enclosure of the high-voltage parts in a shockproof container. Most x-ray generators for industrial radiography are of shockproof construction, but, where the design is such that high-voltage conductors are exposed, operators should keep at a liberal distance from them, and should guard against the possibility of sparkover to other conductors with which any person may be in contact. The most dangerous situation is to permit the body to form a part of the high-voltage circuit, either across the tube leads or terminals, or between a high-potential lead and a low-potential lead or a grounded conductor.

Exposed high-potential leads should be surrounded with grounded or insulated shields, and all doors should be equipped with interlocks to insure that the high voltage is off before access can be had to the conductors. The interlocking switches should not close when the door is shut, but should require some extra operation, performed outside the room housing the high-tension apparatus, before the circuit can be re-energized.

High-voltage condensers are a particular hazard. They should be automatically short-circuited before access to them is possible.

Audible and visible warning signals should be provided in all rooms containing exposed high voltage equipment.

Although high-potential circuits do not extend into the processing room, low-potential electrical outlets and fixtures may present a hazard under some circumstances. As a safeguard, the exposed portions of switches, plug outlets, lamp sockets, and the like should be composed of insulating materials, and, where exposed metal parts are employed, these should be grounded. No electrical device should be touched with the wet hands or while any other part of the body is in contact with a grounded conductor, such as a water connection, processing tanks or fluids, or a concrete floor. In reaching for any electrical fixture, the "one-hand rule" should be followed by keeping the other hand away from all objects. Voltages of 110, or even less, may prove fatal if the electrical contacts to the body are made on the moist skin. These same precautions should also be followed in handling the controls of the x-ray apparatus.

X-ray operators should be familiar with methods of applying artificial respiration, in case it becomes necessary to revive a victim of electric shock.

Protection References

American Standards Association, *Safety Code for the Industrial Use of X-rays.* Z54.1-1946.**

Bureau of Standards Handbook HB20, *X-ray Protection.**

Bureau of Standards Handbook H23, *Radium Protection.**

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GLASSER, O., QUIMBY, E. H., TAYLOR, L. S., and WEATHERWAX, J. L., *Physical Foundations of Radiology*, Paul B. Hoeber, New York, 1944: Chapter XIX, Roentgen Ray and Radium Protection, p. 350.

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*For sale by the Superintendent of Documents, Washington, D. C., 10 cents.

**For sale by the American Standards Association, 70 East 45th Street, New York 17, N. Y., $1.50.

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APPENDIX III

UNSATISFACTORY RADIOGRAPHS

CAUSES AND REMEDIES

I. HIGH DENSITY
- A. *Cause*—Overexposure
  - 1. Incorrect exposure factors
    Remedy—If feasible, view radiograph with greater intensity of illumination; otherwise, decrease exposure by at least one third. Also check meters and x-ray timer to be certain they are in adjustment.
- B. *Cause*—Overdevelopment
  - 1. Development time too long; temperature of developer solution excessively high; or combination of both
    Remedy—See pages 68 and 69; check accuracy of time and temperature.
- C. *Cause*—Appreciable fog
  See section "Fog," page 110

II. LOW DENSITY
- A. *Cause*—Underexposure
  - 1. Incorrect exposure factors
    Remedy—Increase exposure by 40 per cent or more.
- B. *Cause*—Underdevelopment
  - 1. Development time too short; temperature of developer solution excessively low; or combination of both
    Remedy—See "Remedy" I—B—1, above.
  - 2. Weak developer solution
    Remedy—Discard and make new developer solution, using *Kodak Liquid X-ray Developer and Replenisher* or *Kodak Rapid X-ray Developer* in proper quantities. Check capacity of tank; be certain tank does not leak; or water bath flow over into tank.

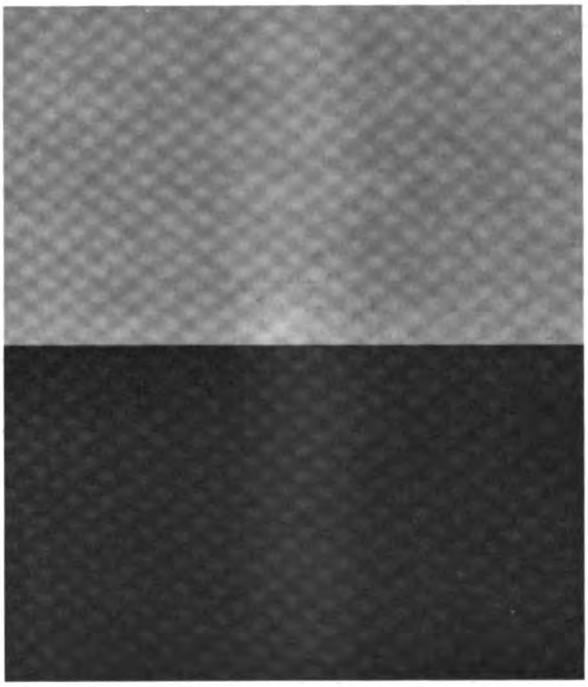

Fig. 93—Lowered density (top) will result if any intervening material such as paper separates the lead screen from the recording film and may introduce an electron shadow picture of the intervening material.

III. HIGH CONTRAST
- A. *Cause*—Insufficient penetration
  - 1. Kilovoltage too low
    Remedy—Increase kilovoltage. It may help to view dense portions of the radiograph, with increased intensity of illumination.
- B. *Cause*—Overdevelopment
  Remedy—See "Remedy" I—B—1, above.
- C. *Cause*—Use of film having too high contrast
  Remedy—Use film of lower contrast; see pages 56, 57 and curves, pages 87, 91.

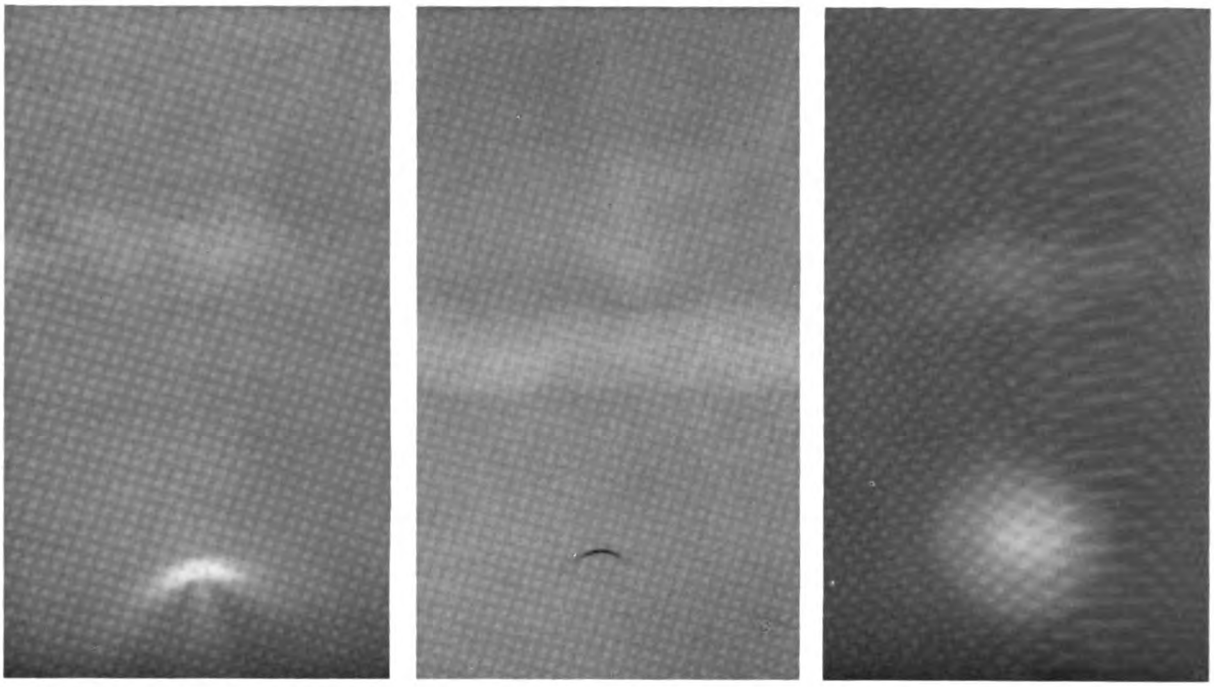

Fig. 94—Proper consideration in the handling of film will prevent such pressure marks as are shown above. "Crimp marks" resulting from poor handling of individual sheets of film before exposure (left), and after exposure (center). Irregular low densities at right are pressure marks caused by heavy object which was dropped on film holder during setup before exposure.

IV. LOW CONTRAST

- A. *Cause*—Excessive penetration
  - 1. Kilovoltage too high
    Remedy—Decrease kilovoltage.
- B. *Cause*—Underdevelopment
  Remedy—See II—B—1 and II—B—2, page 109.
- C. *Cause*—Use of film having insufficient contrast
  Remedy—Use film of higher contrast. See III—C, page 109.

V. FOG

- A. *Cause*—Exposure of film to light that is not safe
  - 1. Light leaks in processing room
    Remedy—With all lights in processing room out and bright lights in adjoining rooms turned on, examine for light leaks; seal any noted.
  - 2. Prolonged exposure to light of safelight lamp
    Remedy—Check safety factor as described on page 81.
  - 3. Safelight lamp containing lamp of wattage higher than specified
    Remedy—Use lamp of wattage indicated on safelight lamp.
  - 4. Bleached safelight. (Faded filter dyes may result from overheated safelight if lamp of high wattage is employed.)
    Remedy—Replace safelight.
- B. *Cause*—Exposure of film to x-radiation (see "Protection of X-ray Film in Storage," pages 62, 63)
  - 1. During delivery or transport within department
    Remedy—Make proper arrangement with dealer; be certain x-ray tube is not operating when film is carried about.
  - 2. While stored
    Remedy—Test protection by placing loaded *Eastman X-ray Exposure Holder* having lead strip on exposure side in location where the film supply is kept. Develop film after two or three weeks; if image of strip is noted, safeguards are not adequate.
- C. *Cause*—Exposure of film to gamma radiation
  Remedy—Use recommended precautionary measures in storing and handling radioactive substances; see "Protection of X-ray Film in Storage," pages 62, 63.

D. *Cause*—Overdevelopment
Remedy—See "Remedy" I—B—1, page 109.

E. *Cause*—Developer solution incorrectly mixed
Remedy—See "Remedy" II—B—2, page 109.

F. *Cause*—Prolonged inspection of film during development
Remedy—Do not inspect films until they are adequately fixed and dry; rely on time-temperature method to indicate correct development.

G. *Cause*—Developer solution contaminated
Remedy—See "Mixing Processing Solutions," page 67.

H. *Cause*—Deterioration of film resulting from storage in a location where temperature and humidity are high
Remedy—Maintain a minimum film stock; use film carrying nearest expiration date first; store film in cool, dry place; see "Protection of X-ray Film in Storage," pages 62, 63.

VI. STREAKS

A. *Cause*—Failure to agitate film during development
Remedy—Move films occasionally so developer near surface of films is replaced by stronger solution. See page 69.

B. *Cause*—Inspection of film during development —If films are held in front of safelight during development, developer runs across film, producing uneven reduction of emulsion, resulting in streaks
Remedy—Avoid handling films until fixed.

C. *Cause*—Interaction of developer and fixer
Remedy—Use acid stop bath between developer and fixer. See page 73.

D. *Cause*—Film drying streaks
Remedy—Use *Kodak Photo-Flo* in final water rinse before drying film, or use viscose sponge to remove water drops from film before drying.

VII. YELLOW STAIN ON RADIOGRAPH

A. *Cause*—Prolonged development in old, oxidized developer solution
Remedy—Discard developer solution and replace with fresh solution.

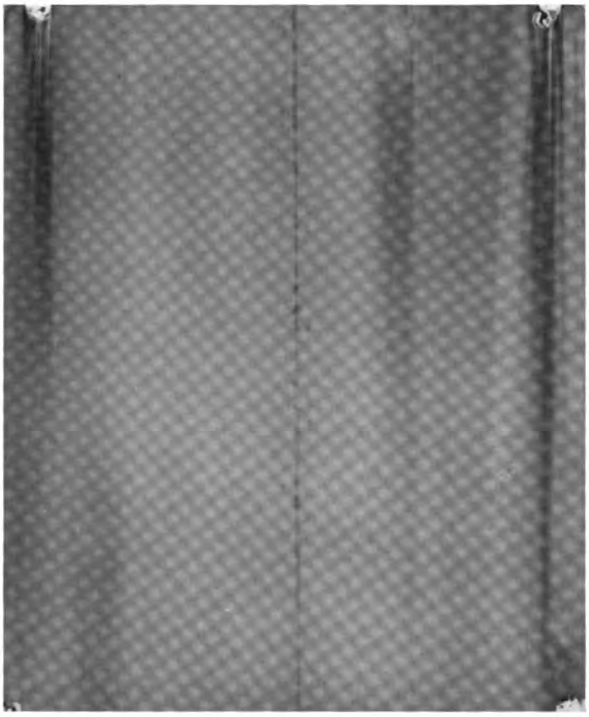

Fig. 95—The use of hangers which have not been adequately washed free of processing solution can create severe streaks on the next film developed with such hangers. Continuation of such practice may so contaminate the developer that stained films and shortened developer life result.

B. *Cause*—Omission of rinsing after development
Remedy—Thoroughly rinse films in clean water before placing in fixer solution; see "Rinsing" and "Stop Bath," page 73.

C. *Cause*—Exhausted fixer solution
Remedy—Replace fixer solution frequently; see "Fixation," pages 73-75.

VIII. WHITE SCUM ON RADIOGRAPH

A. *Cause*—Use of fixer solution that appears milky from a precipitation of aluminum sulfite. May be result of:

1. Incorrect mixing of fixer solution
Too warm when mixed, or mixed too rapidly, or without stirring.
Remedy—Use *Kodak Liquid X-ray Fixer and Replenisher* or *Kodak X-ray Fixer* following directions on package.
2. Developer solution carried over to fixer solution, in film emulsion
Remedy—Thoroughly rinse films in clean water before placing in fixer solution; see "Rinsing" and "Stop Bath," page 73.

IX. RETICULATION (Puckered or netlike appearance of radiograph surfaces)

A. *Cause*—Sudden extreme temperature changes in processing

Remedy—Maintain all processing solutions, and water for rinsing and washing, at as near same temperature as possible; use fixer solution that will provide adequate hardening action.

X. FRILLING (Loosening of emulsion from base)

A. *Cause*—Warm or exhausted fixer solution with no hardening action

Remedy—Control temperature; replace fixer solution frequently.

B. *Cause*—Processing solutions at high temperature

Remedy—See "Remedy" I—B—1, page 109.

C. *Cause*—Prolonged washing at high temperatures

Remedy—Increase rate of water flow through tank, and wash for recommended time; see "Washing," pages 75, 76.

XI. BLISTERS

A. *Cause*—Reaction between alkaline developer and acid fixing bath will form carbon dioxide gas

Remedy—Rinse films thoroughly, see page 73. If stop bath is used, make sure acidity is not too high. Use *Kodak Liquid X-ray Developer and Replenisher* or *Kodak Rapid X-ray Developer*, which have no blister-forming reaction with acid fixing bath.

XII. POOR DEFINITION

A. *Cause*—Excessive object-film distance

Remedy—Decrease distance between object and film; if that is impossible, increase focus-film distance; see pages 9 and 10.

B. *Cause*—Employment of tube with large focal spot

Remedy—Use tube with smaller focal spot, or increase focus-film distance; see pages 9 and 10.

C. *Cause*—Poor contact between film and intensifying screens

Remedy—Check contact; see pages 22, 23.

D. *Cause*—Coarse grain of intensifying screens

Remedy—Change to lead-foil screens or to direct x-ray film; see pages 19 and 23.

E. *Cause*—Coarse grain of film

Remedy—Use a finer grained *Kodak Industrial X-ray Film;* see tables on pages 56, 57, 60.

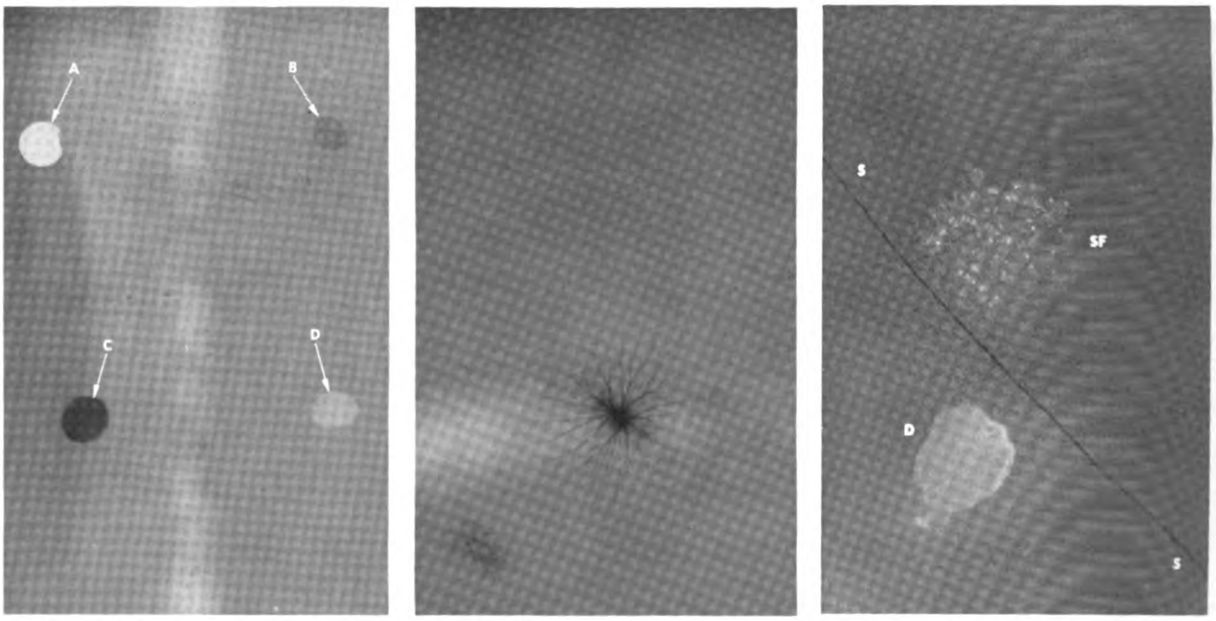

Fig. 96—Left—Film splashed before processing with A, Fixer; B, Water; C, Developer; D, Stop bath. Center—Static marks resulting from poor film-handling technic. Right—Lead screen blemishes—SS, increased film density from deep scratch; SF, decreased density from imbedded particles such as steel filings; D, dried splash of processing solution.

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